Economic Optimization Analysis of Chengdu Electric Community Bus Operation

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Abstract. In recent years, the government has strongly supported and promoted electric vehicles and has given priority to demonstration and popularization in the field of public transport. The economy of public transport operations has drawn increasing attention. In this paper, Chengdu wireless charging pure electric community bus is used as the research object, the battery, air conditioning, driver’s driving behavior and other economic influence factors were analyzed, and optimizing the operation plan through case data analysis, through the reasonable battery matching and mode of operation to help businesses effectively save operating costs and enhance economic efficiency.

1. Introduction
At present, many scholars at home and abroad have done research on the economy of new energy vehicles. These studies can be divided into two categories in genera: the first category is economic evaluation from the point of energy conservation and emission reduction or energy utilization, such as Yang Feng and other scholars, using the “energy rate” as an indicator, selecting Toyota RAV4 electric cars and fuel cars as the evaluation object and analysising the economy of both, it was concluded that the energy consumption cost of pure electric vehicle is superior to that of traditional fuel vehicle under the same condition. Wang Zhenpo and other scholars put forward that the energy utilization ratio is a comprehensive evaluation parameter for the power performance and energy consumption economy of pure electric vehicles, which provides relevant theoretical basis for energy-saving optimization of electric vehicles. The second type is economic evaluation and analysis based on the flow of vehicle lifetime funds. For instance, Zeng Ming[1] and other scholars set up the evaluation model of the economic benefits and environment of HEV from the entire life cycle of the automobile, Which concluded that HEV will be more competitive in the future, and they made some suggestions for the future development of electric vehicles. Wan Jian[2] and other scholars made a dynamic analysis of the economics of new energy vehicles and established an economic analysis model based on the time value of funds. They also made an economic comparison and analysis of the three buses BEB, BEB and CDB. These scholars have made a good theoretical basis for the economic
research of pure electric vehicles and which also have good reference value, but these lack the research on the operating economy of pure electric public vehicles. Therefore, this paper combines with the actual situation of Chengdu wireless charging pure electric community bus operation and analyzes its economy, and it is very important and valuable to economically optimize the operation plan.

2. Economic influence factors of pure electric community bus
The difference between the economic evaluation of a pure electric community bus and a traditional fuel bus mainly lies in the following aspects: First, during the driving process of the traditional fuel buses, the time of refueling is short and the number of refueling times is less, while the electric community buses need to be charged, the charging time will affect the electric buses normal departure frequency, and they need to be recharged many times every day, therefore, in the case of the same amount of transport, the total number of pure electric buses will be increased with respect to the total use of conventional fuel buses. Secondly, the pure electric bus needs to build more charging facilities, the costs of pure electric bus maintenance are relatively high, and the power battery is very expensive. Third, the energy consumption evaluation of pure electric buses is different from that of traditional vehicles under different operating conditions and different speeds, the driver's operating level, the weather environment, traffic control, load and so on will have some impacts on energy consumption.

2.1 The impacts of power battery on the economy of electric bus
The only source of energy for electric community buses is the battery. On the one hand, the discharge of the battery is largely affected by temperature. On the other hand, the air conditioner of the electric bus consumes a large amount of energy. The opening of the air conditioner seriously affects the driving range of the bus. Ambient temperature for air conditioning requirements are different, buses don’t have to open the air conditioner in some seasons, such as most of the time in Chengdu in spring and autumn buses don’t open the air-conditioned. Therefore, whether the air conditioning turned on and power battery performance are important factors affecting the economy of electric buses.

In recent years, the rapid development of pure electric vehicles, lithium-ion batteries are widely used, from the power considerations, the more mature lithium-ion batteries are mainly two kinds, namely the ternary materials and lithium iron phosphate batteries. Comparatively speaking, the energy density of ternary material is more high, the technology and safety of lithium iron phosphate battery is relatively good. Considering all aspects, the city buses mainly use the lithium iron phosphate batteries. At present, the price of lithium-ion battery is still high, so that the price of pure electric vehicles enhance a lot. From the market conditions in 2015, the domestic price of lithium iron phosphate battery is about 2000 yuan / Kwh, only the cost of the battery accounts for 40% to 50% of the cost of the vehicle, there is still a lot of technical space in terms of cost.

2.2 Economic impact of air conditioning on electric buses
In electric vehicles, the total system energy consumption of air conditioning accounted for more than 60% of the total auxiliary system, which has a great impact on the economy of electric vehicles, therefore, electric vehicles on the air conditioning energy efficiency requirements are very high. In theory, the driving range of electric vehicles when turning on the air conditioners is related to the speed of the electric vehicles, and the driving range increases as the speed
increases. The reason is relatively simple, assuming that driving 100km distance, If the speed of 50 km / h goes through the entire journey and the air conditioning takes 2 U, the whole journey of 100km/h is reduced by half as time. However, in actual vehicle driving, the higher the driving speed is, the longer the driving range is. However, the higher the speed is, the lower the power consumption per unit air conditioner is, but the greater the driving resistance (wind resistance, rolling resistance, etc.) the higher power consumption of per mileage overcoming the driving resistance. If the electric car turn on the air conditioner, then the driving range will greatly reduce. Therefore, in the economic evaluation of electric vehicles, the opening or closing of the air conditioning has a great impact on the results.

2.3 The impact of driving behavior on energy consumption
Because the electric vehicles are motor-driven, electric community buses do not have idling conditions and their operating characteristics can be reduced to acceleration, deceleration and uniform speed. The operation change of the driver in the constant speed process is less, transient characteristics of the vehicle is not obvious, thus the uniform process of driving behaviors have little effect on energy consumption. The main effect of energy consumption is the behaviors of acceleration and deceleration, and the classic acceleration or deceleration of the pure electric community bus is the process of entering and leaving the station. During the process of outbound, the driver has an expected value for the final speed of the station. The expected speed has a certain relationship with the route. The higher the expected value, the faster the driver accelerates and the faster the station exits. The more energy is consumed. Process. The distance between bus stops is fixed. The higher the proportion of high accelerations is, the more the number of quick brakes is, the greater the fluctuation of positive and negative accelerations are, and the worse the driver's driving habits are, then the poorer the energy consumption performance is.

3. Economic optimization analysis of operational electric bus
The model of the study is a pure electric bus produced by Chengdu Shudu Bus Company. The electric bus is loaded with 30 people and the battery type is lithium iron phosphate battery. The nominal capacity of the battery pack is 39.27 Kw•h, and the charging mode is wireless charging. The operation route is Chengdu 1058 community bus operation route, and 1058 is the first commercial bus line of wireless charging community bus in China. There are 2 charging stations in the whole line. One is set at the starting point and the other is set at the intermediate station.

3.1 Test data collection
Pure electric buses are much more expensive than conventional fuel buses. Therefore, the actual cost of a vehicle is an important factor in its analysis of operating costs. In the case of meeting the operating requirements, the minimum amount of vehicle input and the lowest battery cost should match. In order to draw the best economic plan, we need to test and record the trial operation of 1058 pure electric community bus firstly. Testing parameters include mileage, driving time, the remaining power of car recorder, the controller temperature, power meter readings, charging time, data records shown in Table 1. Full load during the test, but do not stop by the passengers.

Table 1. Test data for pure electric Community bus
3.2 Calculation of optimal vehicle configuration number

3.2.1 Power consumption calculation of peak time and Off-peak time

- Peak time without air conditioning running power consumption per kilometer of electricity: $\text{Peak time running power consumption per kilometer} = \frac{\text{reading after the second charge} - \text{reading after the second charge}}{\text{second mileage}} = \frac{(196.8-178.1)}{22} \approx 0.85 \text{Kw•h/Km}$

- Off-peak time air conditioning run per kilometer consumption of power grid: $\text{Off-peak time air conditioning run per kilometer} = \frac{\text{after the third charge reading} - \text{third charge after reading}}{\text{third mileage}} = \frac{(212.5-196.8)}{18} \approx 0.87 \text{Kw•h/Km}$

- Off-peak power consumption per kilometer peak energy: $\text{Off-peak power consumption per kilometer peak energy} = \frac{\text{after the first reading of the charge} - \text{before reading}}{\text{first mileage}} = \frac{(178.1-163.7)}{22} \approx 0.65 \text{Kw•h/Km}$

3.2.2 Calculation of turnover time from peak time to off-peak time

(1) Calculation of stop time

Chinese Automotive Technology Center statistics, the cost of our typical city road bus idle time for the entire circulation time of 27.9%, because the electric vehicle is driven by a motor, so the electric community bus does not exist idle condition, operating characteristics can be simplified as acceleration, deceleration, speed. 1058 bus route for clockwise loop running. Don't wait for the red lights, this paper considered idle time is equal to stop time. In Table 1, the average one-way travel time is 25min, the total idle time (stop time) “n” can be obtained by the following formula:

\[
27.9\% = \frac{n}{n + 25}
\]

Calculated by the formula can be “n = 9.7min”, therefore, one-way travel time:

- one-way time = one-way travel time + Total stop time = 9.7 + 25 = 34.7 min
- stop time = Total stop time / Number of intermediate stations = (9.7 × 60) / 17 = 34 s

(2) Calculation of turnover time

The departure interval of Chengdu public transport morning and evening peak time is about 5min / trips, The departure interval of off-peak is about 10min / trips. Bus 1058 runs at 34.7min in one-way travel (lap time). Peak-time stop time of the start and terminus is 5min. Therefore:

- Turnover time of peak time = one-way time + peak time stop time of the start and
Turnover time of off-peak time = one-way time + off-peak time stop time of the start and termius = 34.7 + 5 = 39.7 min

In order to facilitate the calculation, the turnaround time will be rounded by 18s, that is, the turnaround time of each bus peak will be 40 minutes and the peak turnaround time will be 45 minutes. In other words, it takes 40 minutes for each bus to start another bus after the rush hour.

A turnaround time 40min departure situation shown in Table 2.

| Time (min) | 0  | 5  | 10 | 15 | 20 | 25 | 30 | 35 | 40 |
|------------|----|----|----|----|----|----|----|----|----|
| Departure bus | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th | 1st |

(3) At least the required number of buses

Each peak time lasts 2 hours. According to Table 2 above, only 8 community buses are required to operate for 3 laps per vehicle to meet the normal operation of the line. Due to less traffic at off-peak time, departure interval will be longer, and 8 community buses are sufficient to operate.

3.3 Minimum battery capacity ratio

3.3.1 Each car daily power consumption calculation

The total distance of 1058 community bus is 5km, starting from the charging station to the origin station and from the terminal back to the charging station total mileage is 3km. Driving laps at peak time = (60 × 4) / 40 = 6 laps, driven mileage at off-peak time = (60 × 10) / 45 ≈ 13 laps. Air conditioning power consumption per kilometer is about 0.2Kw•h

- Driven mileage at peak time = Driving laps at peak time × One-way distance = 6 × 5 = 30Km
- Driven mileage at off-peak time = Driving laps at off-peak time × One-way distance = 13 × 5 = 65Km
- Daily consumption of electricity per car per day = Driven mileage at peak time × Energy consumption per mile during peak time × Energy consumption per mile during off-peak time + the mileage of returning to the station × energy consumption during off-peak time = 30 × 0.87 + 65 × 0.67 + 3 × 0.67 = 71.66Kw•h

3.3.2 Charging time of Average per unit

The 1058 Shudu bus pure electric community bus nominal voltage is 377.6V, the nominal discharge capacity is 104mA • h, it can be calculated that the Battery nominal charge = nominal voltage × nominal discharge = 377.6V × 104mA • h = 39.27kw • h.

- The first test battery power consumption = (1-70%) × 39.27Kw • h = 11.78Kw • h = the first charging amount
- The second test battery power consumption = (1-61%) × 39.27Kw • h = 15.32Kw • h = the second charging amount
- The second test battery power consumption = (1-61%) × 39.27Kw • h = 15.32Kw • h = the second charging amount

The charge time of per battery unit can be obtained by the Table 1:

- The first test per unit charging time = first charging time / first charging amount = 36 × 60 / 11.78 = 183.36s / Kw • h.
- The second test per unit charging time = second charging time / second charging amount
\[ = 41 \times 60 / 15.32 \approx 160.57 \text{s} / \text{Kw} \cdot \text{h}. \]

- The third test per unit charging time = the third charging time / third charging amount = 41 \times 60 / 13.35 \approx 184.27 \text{s} / \text{Kw} \cdot \text{h}. 

- Charging time of Average per unit = total charging time / total charging amount = (36 + 41 + 41) \times 60 / (11.78 + 15.32 + 13.35) = 175.03 \text{s} / \text{Kw} \cdot \text{h}. 

3.3.3 Daily recharging time and recharging amount

According to the calculation in 3.3.1, the total daily electricity consumption of this community bus is 71.66Kw \cdot \text{h}, the intermediate stations stop for 34s and the recharge time is 30s. Recharge time every day = Recharge time in middle station + Recharge time in starting station = Laps count per day \times Recharge time in middle station per lap + Recharge time in start station at peak time + Recharge time in start station at off-peak time = 19 \times 30 + 6 \times 5 \times 60 + 12 \times 10 \times 60 = 9570s. Therefore, the battery charging amount per car = daily recharging time / average per unit charging time = 9570 / 175.03 = 43.38KW\text{h}. 

3.3.4 The minimum battery capacity.

The minimum battery charge = Total daily battery charge - Daily battery replenishment = 60.42-43.38 = 17KW \cdot \text{h}. 

Because the battery can not be completely discharged, lithium iron phosphate battery’s depth of discharge is about 70\%, the battery nominal charge = 17 / 0.7 = 24.3KW\cdot \text{h}. 

Because the battery capacity will gradually decay during its used process. In the case of room temperature and standard discharge rate, when the battery standard discharge capacity decays to the nominal capacity of 70\% or 80\% of the time as the battery end of life time, this paper decay to the nominal capacity of 75\% as the battery end of life time, then The actual nominal battery capacity of a pure electric bus is determined as: 24.3 / 0.75 = 32.4 \text{Kw} \cdot \text{h}.

The test car had a nominal battery pack capacity of 39.27KW\cdot \text{h} when it left the factory, but according to the calculation of this paper, actually only 32.4KW\cdot \text{h} to meet operational needs, reducing the 6.87KW\cdot \text{h}, lithium iron phosphate battery price of 2 ~ 5 yuan / wh, take the price of 3 yuan / wh, then each bus can reduce the investment of 6.87 \times 1000 \times 3 = 20.61 million yuan, the entire line 8 community bus can reduce input 2.0611 \times 8 = 165,444 yuan. The parameter of the single-cell lithium iron phosphate battery for the 1058 electric bus is voltage 3.2V, nominal discharge capacity 104AH, actual nominal capacity (KW \cdot \text{h}) = (battery voltage (V) \times battery capacity (AH)) / 1000, thus, battery voltage = 3.2 \times 1000 \times 104 = 311.5V. The number of required single cells = battery voltage / cell voltage = 311.5 / 3.2 = 97, only 97 sections of 3.2V / 104AH small capacity battery in series can meet the normal operation of electric community bus every day.

4. Conclusion

Having based on the analysis of three economic factors such as power battery, air-conditioner and driver's behavior of pure electric community bus and the actual test collection data, the best economical operation plan is analyzed, the optimal vehicle configuration of the bus line and the battery capacity of daily operation, as well as the power charging during operation, are calculated, and the minimum battery capacity ratio is obtained. The result shows that the optimal number of vehicles in this bus line is 8, the minimum bus voltage in each community bus is 311.5V, and the single cell capacity is 104A\cdot \text{h}, which is composed of 97 3.2V / 104AH small capacity cells in series to meet the normal operation of pure electric community bus every day.
day, significantly reducing the battery capacity than the original car, reducing the cost of enterprise investment.

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