Study of the EV Battery Pack Attended Mode

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Abstract
In order to deeply understand the influence on the performance of the Battery pack, which comes from the battery pack attended mode, the battery pack attended mode is studied. Through lots of running experiments of EV, the models of battery pack attended mode are established and the influencing factors that influence the reliability of battery pack attended mode and voltage inconsistency are analyzed. The selection principle of attended mode is brought forward.

Keywords
battery pack model, charge rule, discharge rule, reliability, inconsistency

1. INTRODUCTION
In order to solve the problems of energy consumption and environmental pollution EVs have become the inexorable trend of the automobile industry development. The EV project is set up as one of the major projects in the Chinese program "863". As the key technology of EV the battery always baffles the development of EV industry. Under this condition, the battery technology hasn't qualitative change. So in order to increase the battery service performance it is very important to take measures on use. The battery pack attended mode has influence on battery pack reliability and inconsistency.

2. THE BATTERY PACK RELIABILITY
2.1 The theory of reliability
The probability that one component can work up to snuff is the component reliability. The probability that one system can work up to snuff is the system reliability. Supposing the component reliability is Ri ($0<Ri<1$) and the components are independent of each other, whether or not they can work. Under this instance, the reliabilities of 2 attended modes are calculated. The models are shown as Figure 1.

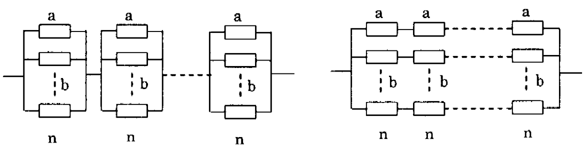


Fig. 1 Reliability analysis model

Utilizing the above-mentioned theory the reliability that first m components connect parallel, then n components connect series can be calculated. The equation is:

$$R_s = \prod_{i=1}^{n}[1-(1-R_i)^m] \quad (1)$$

The reliability that first m components connect series, then n components connect parallel is:

$$R_s = 1-\prod_{i=1}^{m}[1-R_i]^n \quad (2)$$

2.2 Battery model reliability calculating result
Supposing that the battery reliability is equal and Ri =0.99, lithium-ion batteries are used as a sample. They are fitted in one kind of electric bus. The bus is shown as Figure 2. The number of the cells is 432.

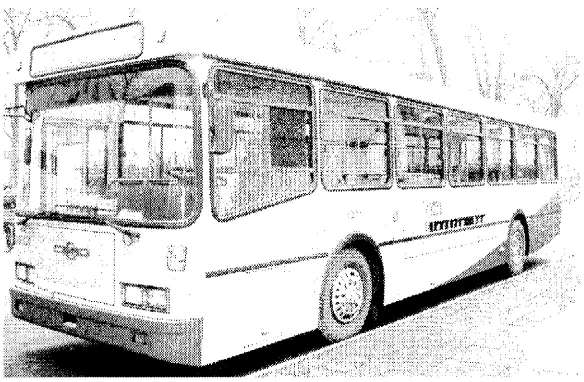


Fig. 2 The fitted Li-ion battery E-bus

(1) First parallel, then series. m=4, n=108 (the model is used by the testing bus, Figure 1)

$$R_s = [1-(1-0.99)^4]^{108} = 0.999 \quad (3)$$

(2) First series, then parallel is as this:

$$R_s = 1-[1-0.99^{108}]^4 = 0.807 \quad (4)$$

From the calculating result, we can know that the first model reliability is far better than the second one.

2.3 The reliability of model combination

On the base of 2 attended modes, lots of attended modes can be fit together. That is to say several batteries are serial, then some of these packs are parallel, at last several of these combinations are assembled into a battery pack system. The basis form shows as Figure 3. The reliabilities of those attended modes are between the above-mentioned 2 modes. The reliability of the subsystem can be calculated by formula (1). The combination of subsystems can be calculated by formula (2).

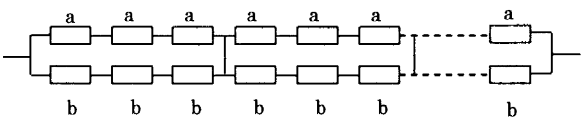


Fig. 3 Reliability model of combination

3. PERFORMANCE INFLUENCE CAUSED BY BATTERY INCONSISTENCY

3.1 The reason of causing the battery inconsistency

The battery inconsistency is the differences of voltage, internal resistance and capacity in the same specific battery. There are 2 reasons to form battery inconsistency. (1) In the course of production, the material is not completely the same. So the active degree of the material has some difference. Because of this the battery capacity, internal resistance and so on in the same group can't be completely the same. (2) Along with the use, the density of the electrolyte, temperature, discharge degree and airing condition have influence on the battery. That can enhance the battery inconsistency.

Basing the differences of theory and influence style, the inconsistency can be distinguished as three kinds: capacity inconsistency, resistance inconsistentncy and voltage inconsistency. In practise the voltage inconsistency is the most visualized in the inconsistency. It is also easiest to measure.

3.2 The representation of battery inconsistency

In the different discharge degree, the data of static inconsistency can be gained through measuring the voltage of the battery in one pack. Figure 4 shows the voltage inconsistency of the Li-ion batteries that are used in one of the electric buses. When they are charged completely, the voltage inconsistency of the batteries can be ensured, but the battery will show inconsistency after 40-50% discharge. When the battery discharges up to 80%, the voltage inconsistency will be an important factor, which affects the the driving range. In this condition the highest voltage is 3.3V and it is in the working voltage. But the lowest is 2.5V and goes beyond the

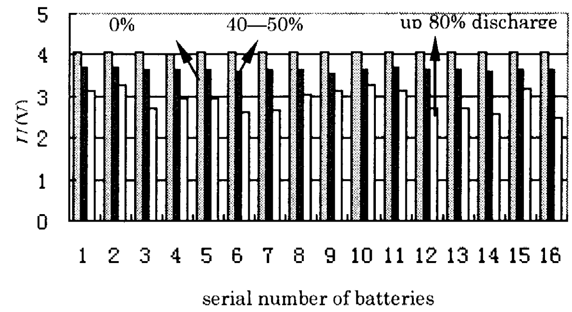


Fig. 4 Voltage inconsistency of different discharge's depth

working voltage. The voltage difference is 0.8V. if the E-bus goes on running, the battery of lower voltage will engender permanent breakage. If the bad battery is not found in time, it will become a load in the pack and influence the work of the other batteries. As a result the life cycle of the battery pack will decrease. So if the inconsistency is obvious in specific discharging degree, the EV can't go on running. The driving range is limited by this characteristic.

In the course of the EV driving, the battery inconsistency is also very obvious. As an example Figure 5 shows the discharge curve of 2 Li-ion batteries that were used in E-bus. The 2 batteries are connected in series. In this figure the upside is the current change in the course of EV driving. Correspondingly the underside in the voltage change. Before the discharge course the voltage of the 2 batteries is the same in the gross. In the course of dicharge the voltage show difference gradually. In some moment the largest voltage difference can reach 0.15 V. In this figure it can be seen that the voltages are interlaced. On the whole the voltage change is only relative to the discharge current. The larger the current, the lower the voltage becomes. Along with the discharge course the balanced voltage is descended step by step.

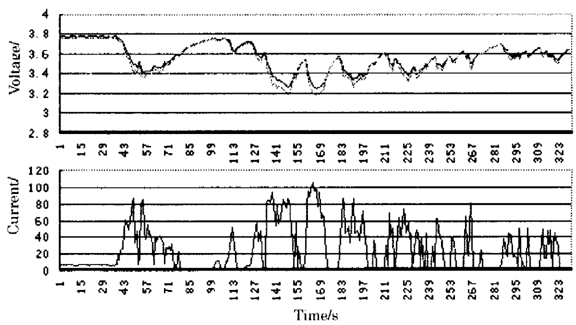


Fig. 5 Voltage inconsistency in dynamic state

3.3 The influence on voltage inconsistency caused by attended mode

The main effect of the voltage inconsistency consists in the mutual charge of batteries in parallel circuit. When one cell voltage is lower than others, the others will charge to this one. That shows as Figure 6. Supposing the voltage E1 is lower than E2, so the current direction is shown in this figure. That looks as the charge circuit. This attended mode results in a small increase of capacity in low voltage batteries, but at the same time sharp decrease of capacity in capacity of high voltage batteries. The energy is wasted in the course of a mutual charge of batteries and can't reach expectant output.

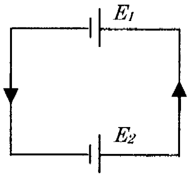
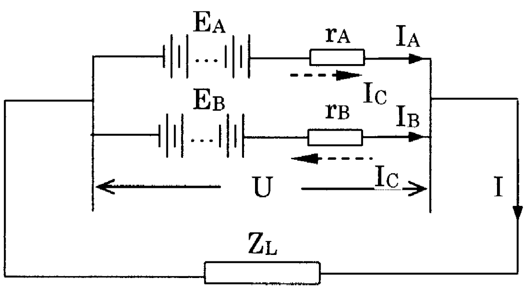


Fig. 6 Voltage inconsistency in parallel

For example, the 2 attended modes in Figure 1, firstly (a) is studied. Because of the voltage inconsistency of each battery, the voltage difference maybe step up or counteract one another in the two serial packs. Theoretically the two probabilities are the same. In practice the first always appears. Through actual measurements the battery internal resistance is 1-30mΩ. A li-ion battery is always used in EV. Its internal resistance is 2-6 m Ω . Supposing the value is 3 m Ω , 100 Li-ion cells in serial, and 2 packs in parallel. So the systematic internal resistance is 0.15 Ω . If the voltage difference of the 2 packs is 1V, there will be 6-7A current in the system. The power consumption is 5-7watt. Along with the depth of discharge, the voltage difference maybe on the increase, the energy consumption will enlarge too. In the course of EV driving, this will baffle the discharge to the driving system. Supposing $E_A > E_B$ in Figure 7, the charge current in each pack is reserved to the discharge current in branch circuit B. The result of the attended mode is analyzed in detail.



E_A, E_B –Total voltage of 2 branch circuits;
I_A, I_B –Current of 2 branch circuits;
I_C –Current of mutual charge;
U, I –Total voltage and current;
r_A, r_B –Internal resistance of 2 branch circuit

Fig. 7 The model of battery pack system

The power output of battery pack is

$$P = UI = U\left(\frac{E_A - U}{r_A} + \frac{E_B - U}{r_B}\right) = U\left[\frac{E_A}{r_A} + \frac{E_B}{r_B} - \left(\frac{1}{r_A} + \frac{1}{r_B}\right)U\right] \quad (5)$$

$$\frac{\partial P}{\partial U} = \frac{E_A}{r_A} + \frac{E_B}{r_B} - 2\left(\frac{1}{r_A} + \frac{1}{r_B}\right)U \quad (6)$$

Supposing $\frac{\partial P}{\partial U} = 0$, so $U = \frac{r_B E_A + r_A E_B}{2(r_A + r_B)}$.

So the largest output power is

$$P_{max} = \frac{1}{4}\frac{\left(\frac{E_A}{r_A} + \frac{E_B}{r_B}\right)^2}{\frac{1}{r_A} + \frac{1}{r_B}} \quad (7)$$

Supposing $r_A = r_B = r$, $P_{max} = \frac{E^2}{2r}$ in $E_A = E_B = E$; as $E_A > E_B$, $P_{max} \le \frac{E^2}{2r}$, the output power is less than the value in the same resistance and voltage.

In Figure 1 (b), though the mutual charge lies in the parallel cells too, the relative voltage difference of a single battery is small and the energy consumption reservedly small too. The effect lies only in several batteries. At the same time this mutual charge in a small range is in favor of the balance in voltage of each battery and supply energy to low capacity battery. The result is remarkable. The statistic distribution of 2 attended modes is shown as Figure 8. That belongs to Li-ion battery. They are fitted on EV and running 5000km. The voltage is measure after they are charged fully for about 10 hours. In this figure that is obvious, the voltage distribution by attended mode in Figure 1 (b) is relatively concentrated and no too low voltage batteries appear. But the voltages of the battery pack that adopts the attended mode in Figure 1 (a) are low at large, the voltage distribution range is large. If they are used unceasingly, the maintenance work such as single charge is necessary. Otherwise this battery pack maybe is destroyed totally.

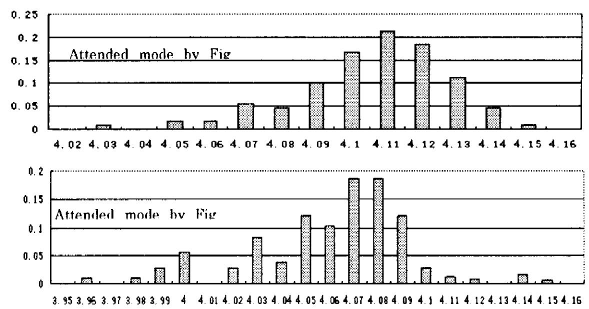


Fig. 8 Voltage distribution of different attended mode after 5000km

4. CONCLUSION

The reliability of battery pack attended modes was discussed. The result is that the reliability of first serial then parallel mode is higher than first parallel then serial;

The trend of voltage inconsistency development caused by different attended mode was analyzed. The result is that first parallel then serial is better than first serial then parallel;

Generally considering the reliability and battery performance development, the first parallel then serial attended mode is advised.

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