

# Characteristic research on lithium iron phosphate battery of power type

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**Abstract.** In this paper, it is the research topic focus on the electrical characteristics analysis of lithium phosphate iron (LiFePO<sub>4</sub>) batteries pack of power type. LiFePO<sub>4</sub> battery of power type has performance advantages such as high capacity, lower toxicity and pollution, operation at high temperature environment and many cycling times in charging and discharge and so on. The charging and discharging characteristics for LiFePO<sub>4</sub> batteries of power type pack have been verified and discussed by the actual experiment. Base on the 12V10AH LiFePO<sub>4</sub> battery was proceeding on charging and discharging test with over high current value and which investigate the parameters such as the internal resistance, the related charge and discharge characteristics of LiFePO<sub>4</sub> battery pack, the actual value of internal voltage and internal resistance of the battery pack and by polynomial mathematic model to approach the accuracy of inner resistance on discharging mode.

## 1 Introduction

The battery is storage and energy conversion components which can be stored in the original physical energy, chemical energy or other type energy and that can be converted into electricity and released to attach circuit for application [1, 2]. In accordance with the energy storage and release methods that can be divided into physical batteries and chemical batteries. The former are convert from the light, heat and other renewable energy to electricity and to storage in batteries or release in transmission line to loadings and consumption the power which the description type are such as solar cell [3], wind power[4], atomic force batteries and so on. Chemical batteries are chemical substances through the material of the redo reaction which by the active substances reactive effect convert from chemical energy to electricity that base on the charging and discharging apply recycle can divided into primary battery and secondary battery. Primary battery just can only discharge once and till to not drive the electrical loading so far. At the end of time in discharging mode that the battery does not chemical substances all played a chemical effect can no longer be able to provide electricity and it cannot be provided by the external power supply at after the full discharge make this battery useless. That is because its electrochemical

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reaction is irreversible by the reasons of electrolyte cannot be restored by recharging step. The secondary battery is chemically converted into electrical energy and can be recharged into a battery by recharging the battery that effect is re-converted into chemical energy and it can be reused. The number of times uses will vary with the material and the application. In general, that exists in the market such as the lead-acid batteries, nickel-cadmium batteries, nickel-metal hydride batteries and lithium family batteries [5]. Different chemical type batteries rely on its working voltage, capacitance and safety of the relationship that made different applications. A lithium battery mainly refers to lithium-ion batteries. At present in the market can be found for the lithium cobalt material, lithium manganese material but the both in the use of security on the doubt there will be cause high temperature resulting in explosion or the decline in capacity of the problem. To improve the lithium batteries to lithium phosphate iron (LiFePO<sub>4</sub>) batteries [6, 7, 8] for these problems, can eliminate the user's security concerns. In this paper, the charging and discharging characteristics of power type LiFePO<sub>4</sub> batteries pack will be by the actual experiment to verify and discussion. The study steps are following :

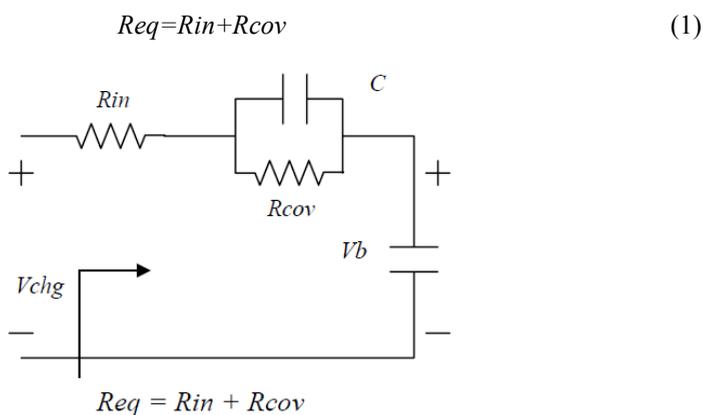
- 1) Explore and compare the dynamic characteristics of different secondary batteries of power type.
- 2) Discuss and decide the lithium iron phosphate (LiFePO<sub>4</sub>) battery of power type pack rated to voltage and capacity as the subject of research.
- 3) Discussion on the parameters and characteristics of power type LiFePO<sub>4</sub> pack in charging mode and discharging mode.
- 4) To investigate the power type LiFePO<sub>4</sub> pack by charging and discharging test with heavy duty.
- 5) Analyze the charging and discharging curves of LiFePO<sub>4</sub> of power type with the polynomial method.
- 6) To find the power type LiFePO<sub>4</sub> pack the inner resistance in charging and discharging test with heavy duty to reach the relative errors.

## **2 Comparison with the LiFePO<sub>4</sub> and the other different secondary battery**

Currently on the market mainly using the most extensive secondary battery are lead-acid batteries pack, and lithium batteries such as lithium-cadmium batteries, nickel-metal hydride battery, lithium cobalt battery and LiFePO<sub>4</sub> battery packs. Lead-acid battery because of the widely operating temperature, simple structure, technology is mature and low price characteristics to form the higher usage rate but the lower cycle life and discharge coefficient (or called *Crate*), higher internal resistance and high toxicity caused by high pollution shortcomings to make the replace effect by other chemical Battery packs. in this paper, it is discussed the LiFePO<sub>4</sub> battery packs which have the advantages of high capacitance, low toxicity and no pollution, high temperature environment and good circulation performance under heavy duty charge and discharge mode, and wide sources of raw materials. Compared with other lithium family batteries packs which LiFePO<sub>4</sub> battery packs have high efficiency energy conversion up to 95% and posses the more life cycle up to 2000 times than the other lithium family batteries packs life cycle about from 400 to 500 times. LiFePO<sub>4</sub> battery packs is also very suitable with power supply for electric motors and for power management such as electricity scooter, pure electricity scooter and hybrid cars applications and so on, and in the future will become the mainstream of electric vehicles.

### 3 Internal resistance varying characteristics in charging and discharging mode of LiFePO4 battery pack

In Figure 1 which  $V_b$  is inside voltage of battery pack and  $R_{in}$  is inner resistance of battery pack. Generally, battery equivalent circuit will not show  $R_{cov}$  and  $C$ . The resistance  $R_{cov}$  and capacitor  $C$  in parallel configuration and in series with the former circuit that simulation the in over-voltage states will produce the phenomenon. So that made the analogy charging process of this battery equivalent circuit diagram is more realistic and therefore improves the shortcomings of the linear model and is therefore more accurate than the linear model. And  $R_{eq}$  is the equivalent battery resistance seen by side of the voltage source, since the capacitance  $C$  is the open state so that equivalent over-voltage will produce the phenomenon, and the general battery equivalent resistance  $R_{eq}$  is equal as equation (1).



**Fig. 1.** Battery pack equivalent circuit diagram.

Form view of the battery pack capacity in fixed that the capacity is full or not with its battery pack inner resistance is closely related in charging mode or proceeding. In general, each battery pack capacity of the full percentage greater relative inner resistance will be made greater. In contrast, the smaller the degree of filling of each battery packs company with the smaller its internal resistance. The relationship between the external voltage and the magnitude of the battery pack resistance is by the actual circuit to test and explain.

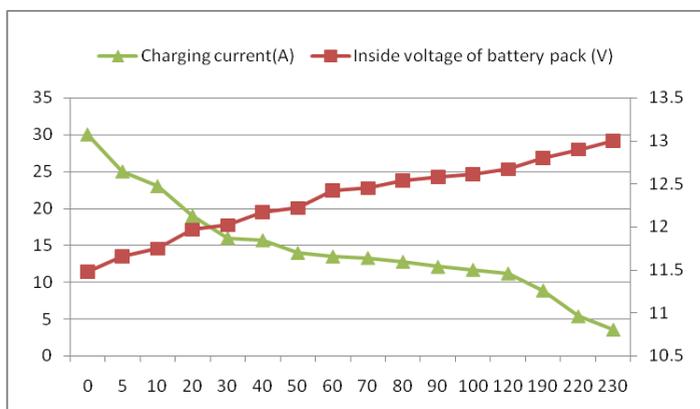
#### 3.1 The relationship between C with the charging voltages and currents

Based on the specification of A123 26650 LiFePO4 battery cell as shown in the Table 1.

**Table 1.** LiFePO4 battery cell specification [9, 10].

Type	A123
Rate voltage	3.3V
Rate capacity	2300mAh
Weight	73g
Charging time	Conventional charging about 1C-2C or 3-4A and fast charging about 5C or 10A.

A constant voltage charging circuit is designed for a 12V 10Ah LiFePO4 battery pack to keep the charging voltage constant and allow the charging current to be less than 3C which let charging current between in conventional charging and fast charging areas. The charging data is shown in Table 2. When the time is 0 for start, the initial value of the voltage is 11.48V and charging current is 30A. When the time passes 5 seconds, the voltage rose to 11.66V and then the charging current dropped to 25A. When the time after 50 seconds which the inside battery pack voltage rose to 12.22V and then the charging current is 14A. According to the design of charging voltage for the battery pack, when the battery pack inside voltage reach the charging voltage will let the charging current become about 0A, that is called full charging. When the time passes 100 seconds, the voltage rose to 12.61V and then the charging current is 11.7A. When the time passes 230 seconds, the voltage rose to 13.00V and then the charging current dropped to 3.2A we can see that when the battery slowly filling the voltage will stabilize, the current will slowly decline. Base on the data we can down the charging curve shown in Figure 2.



**Fig. 2.** LiFePO4 battery pack charging.

**Table 2.** LiFePO4 battery pack charging trace constant with voltage method.

Time(second)	Inner voltage of battery pack (V)	Charging current(A)
0	11.48	30
5	11.66	25
10	11.75	23
20	11.27	19
30	12.02	16
40	12.17	15.7
50	12.22	14
60	12.42	13.5
70	12.45	13.3

80	12.54	12.8
90	12.58	12.1
100	12.61	11.7
120	12.67	11.2
190	12.8	8.9
220	12.9	5.4
230	13	3.6
240	13	3.2

### 3.2 Calculation the dynamic internal voltage and equivalent inner resistance of the battery pack

Figure 3 is a 12V10AHLiFePO4 battery pack for the power source supply and by series with a DC motor which internal resistance  $R_M$  is 0.07 ohm to form a closed loop for measure the battery pack dynamic inner resistance in discharge mode under different voltage equalization. The equivalent resistance  $R_{eq}$  seen from the power supply side is shown in equation (2) and the dynamic internal resistance  $R_{in}$  of the battery pack is shown in equation (3). According to the discharge battery pack voltage level is divided into 13 measurements points shown in table 3. At first time the battery pack side voltage 13.2V, current is 2.8A, supply side equivalent resistance  $R_{eq}$  is 4.71 ohm and the battery pack internal resistance  $R_{in}$  is 4.64 ohm. At sixth time the battery pack side voltage 12.8V, current is 3.3A, supply side equivalent resistance  $R_{eq}$  is 3.88 ohm and the battery pack internal resistance  $R_{in}$  is 3.81 ohm. And at the last time the battery pack side voltage 10.7V, current is 3.3A, supply side equivalent resistance  $R_{eq}$  is 3.24 ohm and the battery pack internal resistance  $R_{in}$  is 3.17 ohm. From the table 3, it is made a result which is the higher the supply voltage with the smaller the discharging current will reach the resistance larger by loading with unchanged or fixed resistance.

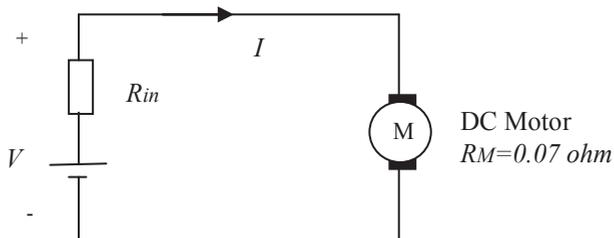


Fig. 3. LiFePO4 battery pack charging.

$$R_{eq} = V/I = R_{in} + R_M \tag{2}$$

$$R_{in} = R_{eq} - R_M \tag{3}$$

With the relationship between the battery internal resistance  $R_{in}$  and the voltage  $V$  in Table 3 that by using the third-order polynomial mathematical model of voltage  $V$  is used to approach the internal dynamic internal resistance  $R_{in}$  and predictive internal resistance

value of the battery, as shown in equation (4). Using the relative error  $RE_V\%$  as shown in equation (5) to confirm the accuracy of the mathematical model and the Table 4 is shown in the table for each voltage class approaching the battery block internal resistance and relative error.

$$Rin = a_0 + a_1 \times V + a_2 \times V^2 + a_3 \times V^3 \tag{4}$$

where

$Rin$ : internal resistance of battery pack  
 $V$ : discharging voltage

$$RE_V \% = \frac{|Rin, actual - Rin, fit|}{Rin, actual} \times 100\% \tag{5}$$

where

$Rin, actual$ : internal resistance of battery pack which equal to  $Rin$   
 $Rin, fit$ : internal resistance approach by polynomial mathematic model.

**Table 3.** LiFePO4 battery pack charging trace constant voltage method.

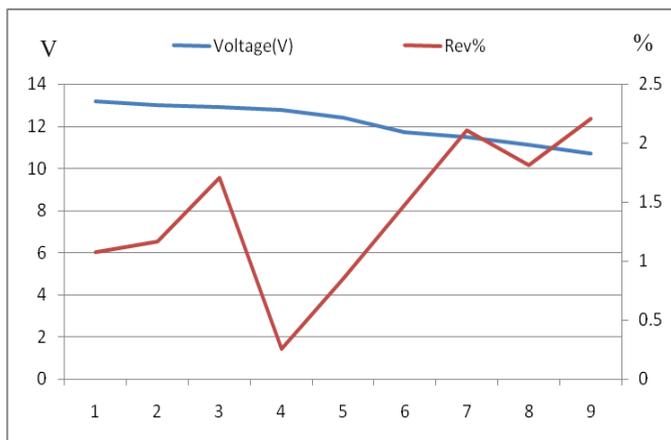
Parameters order	Voltage(V)	Current(A)	$Req$ (ohm)	$Rin$ (Ohm)
1	13.2	2.8	4.71	4.54
2	13.0	2.7	4.81	4.74
3	13.0	2.9	4.48	4.41
4	12.9	3.1	4.16	4.09
5	12.9	3.3	3.91	3.84
6	12.8	3.3	3.88	3.81
7	12.8	3.5	3.66	3.59
8	12.8	3.6	3.56	3.49
9	12.4	3.5	3.54	3.47
10	11.7	3.4	3.44	3.37
11	11.5	3.4	3.38	3.31
12	11.1	3.3	3.36	3.29
13	10.7	3.3	3.24	3.17

It can be seen from Table 4 that the results of the polynomial calculated by the relative error formula (5) and the measured internal resistance of the battery are within 2.21% which the maximum difference value is 0.07ohm and  $RE_V\%$  is 2.21%, and the minimum difference value is only 0.01ohm and  $RE_V\%$  is 0.26% and the total average  $RE_V\%$  is 1.41% , so it can

be resulted, the calculation result of formula (3) is very close to the actual value of internal resistance of battery pack. Figure 4 is relative error chart by polynomial mathematic model.

**Table 4.** The relative error by polynomial mathematic model.

Paramaters order	Voltage(V)	$R_{in,actual}$ (ohm)	$R_{in,fit}$ (ohm)	Rev%
1	13.2	4.64	4.59	1.08%
2	13.0	4.26	4.31	1.17%
3	12.9	4.09	4.02	1.71%
4	12.8	3.81	3.80	0.26%
5	12.4	3.47	3.44	0.86%
6	11.7	3.37	3.32	1.48%
7	11.5	3.31	3.24	2.11%
8	11.1	3.29	3.23	1.82%
9	10.7	3.17	3.10	2.21%
average				1.41%



**Fig. 4.** The relative error chart by polynomial mathematic model.

## 4 Conclusions

For the actual circuit design to do charge and discharge test obtained the battery pack voltage, resistance and other parameters and to determine which each other dependency. And deduce the battery internal dynamic resistance and in order to other applications before the lead operations. In the charging mode, when the charging voltage is fixed that result of the battery voltage, current and internal resistance are closely related to each other.

Similarly, in the discharge mode is also the same. In the discharge mode, the battery internal resistance and the battery potential can be approximated by the mathematical model of the third-order polynomial to the internal resistance of the battery pack and obtain its value. Through the every voltage level to statistics the total relative error is 1.41%. In this article, through the relevant simple circuit can be accurate and quickly know the dynamic resistance of the battery pack and the relevant internal resistance and electricity residue of battery pack.

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