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Characterization and comparison between lithium iron p hosphate and lithium-polymers batteries

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ABSTRACT

Electrochemical storage systems are increasingly employed in stationary and automotive applications. The lithium-ion technology nowadays shows the best features and future development prospects. Nevertheless, lithium-ion chemistries are a lot and there is the need to know in deep their behaviour in relation to the final applications. Among the most used Lithium technologies, the CNR-ITAE has selected two different Lithium technologies: Lithium-Iron-Phosphate ($LiFePO_4$) and Lithium-Polymers to be tested and compared. Indeed, several electrical vehicles developers and electrical network operators are choosing these specific chemistries for their safety, relatively low cost and flexibility in creating customized battery pack. This paper reports the results of several tests carried out in order to investigate the features of each battery technology for stationary and automotive applications. In particular, the capacity reduction (Peukert effect) and the cell efficiency were analysed. Furthermore, tests showed the different relax time effect and the dynamic behaviour of cells subjected to different load profiles compliant with IEC (International Electrotechnical Commission) tests procedures. A final analysis was carried out comparing the main performance indicators (Capacity, Amperometric and Energetic Efficiency, working temperatures, etc.).

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1. Introduction

Nowadays battery improvements are having a growing impact on the energy application field: their increasingly efficient features make them able to provide several and different services [1].

Indeed, in automotive and in stationary applications batteries have already reached a great importance and many efforts have been done in the last years in order to implement and improve their use [2,3]. Several technologies have been studied and now proposed in the global market. In particular, lithium ion batteries show optimal electrochemical properties [3]. Lithium is the metal with the lowest atomic weight, has a high electrode potential (−3.04 V), small size and a very high specific capacity (3.86 Ah/kg) [3,4]. These characteristics make it one of the most suitable elements for the construction of batteries with high energy density and high specific power [4]. Generally, lithium battery are characterized by the metal composition of the cathode. The most used materials in the cathode are the lithiated metal oxide such as $LiMnO_4$, $LiCoO_2$, $LiNiCo_xO_2$ or $LiMn_{1-x}Co_xO_2$ [5].

Although the batteries based on lithium are more and more investigated, often the end users (grid operators, electric vehicles developers, etc.) have not sufficient information about their behaviour when subjected to load profiles, retracing the real final applications. End users look at commercially available lithium batteries, usually having just few information coming from manufacturers, without details on the real operation.

For this reason, there is the need to evaluate the chemistries from the end user point of view, through tests protocols able to highlight advantages or disadvantages of the single chemistry. Further, the direct comparison of two or more lithium batteries could increase the comprehension in the performance evaluation.

This paper focuses on two of the most promising lithium chemistries: lithium polymer (LiPo) and lithium iron phosphate ($LiFePO_4$) [5–8].

Lithium polymer and lithium iron phosphate batteries are investigated both for automotive and stationary porpoises [9,10]. Especially for automotive applications, lithium polymer and lithium Iron Phosphate batteries are directly in competition [9,11] because of their performance characteristics and for the ability to be easily integrated in the narrow vehicles spaces and volumes.

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In the literature, several papers are based on the study or on the developments of the single chemistry, but a direct comparison, to highlight the specific advantages/disadvantages in relation to the specific application, is not present.

This work presents a test campaign performed on commercial batteries with the aim at obtaining in conclusion an overview about applications and potentials, for better addressing evaluations and choices of the readers.

1.1. Lithium-polymer technology

Lithium-polymer battery (abbreviated Li-Poly or LiPo) is a technological development of the lithium-ion batteries.

Lithium polymer batteries are classified according to the typology of treatment of the electrolyte: crystalline polymer, dry polymer, plasticized polymer and solvent doped polymer [12]. Crystalline polymer electrolyte is characterized by low conductivity [12], [13]. Dry polymer electrolyte is composed by a non-crystalline material containing dissolved salt. Plasticized polymer contains organic additives and conductivity is higher than dry polymer because of the greater freedom for molecular motion [13]. Solvent doped polymer can have a single or a double phase structure depending by doping level [15,14]. One of the most used treatment for polymer electrolyte is the plasticized polymer [15]. There are many advantages in this type of construction, compared to the classic lithium-ion battery design:

- the electrolyte [16,17] is less reactive with lithium and no liquid leakage can occur, which enhances the safety;
- no need of any type of metal container, the battery can be lighter and shaped [17];
- possibility to work at high temperature (>60 °C).

Unlike lithium-ion batteries, which are contained in rigid metal containers, polymer cells are manufactured in flexible structure, often folding sheets [17,18] (polymer laminate). Thus, they can be adapted to all forms required for various electronic devices. Cells with polymer electrolyte in gel form generally are considered safer than the most number of lithium-ion batteries because their electrolyte is less reactive than liquid one, having no losses. Lithium polymer batteries are characterized by high energy density (up to 155 Wh/kg) [19] and a high values of C-Rate (in the last manufactured batteries even up to 8 ÷ 15C). A great difference between life cycles declared from manufacturers (over 4500 cycles) and life cycles (less than 1500) [20–22] searched in literature was found. Moreover, these cells have a low self-discharge rate (5% per month) [19] and do not use any toxic or harmful materials. However, they do not have reached yet competitive costs referring to other battery typologies (final price 1.300 ÷ 1.800 €/kWh). In the past some cells have showed a swelling during operation that has compromised the mechanical structure; the reasons for this phenomenon are under investigation even if it seems to be due to hard operation or storage temperature, or the overcoming of the cut off voltage in charge (>4.25 V) and in discharge (<3 V) [23,24].

1.2. Lithium-iron-phosphate ($LiFePO_4$)

This technology is growing rapidly in the energy storage market. The lithium iron phosphate cells show stability in overcharge or short circuit conditions and they can withstand high temperatures [25]. The cells are characterized by a uniform distribution of temperature with a little gradient between the internal and the surface regions [26]. As pointed out for Li-Po batteries, life cycles declared by manufacturer (up to 3500) are very high in comparison with values searched in literature (less than 1500) [27–29].

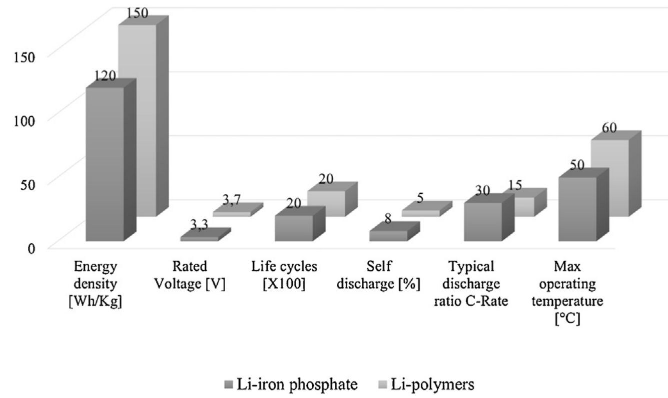

Fig. 1. Lithium polymer and lithium iron phosphate batteries main features.

Generally, the cell rated voltage is 3.2 ÷ 3.3 V. The main features of this battery technology are: safety in abuse conditions due to its high thermal stability, good value of energy density (up to 110 Wh/kg) [28] and high value of C-Rate (up to 25 ÷ 30) [29]. $LiFePO_4$ has a good cyclic stability [31]. Moreover, lithium iron phosphate technology has a competitive cost (whose range is from 500 to 1.400 €/kWh).

Fig. 1 shows the main features of the two technologies investigated. Data on the costs have been evaluated through a market research considering different battery manufacturers and are referred to the single cells.

2. Experimental and discussion

2.1. Main features of the cells under test and test equipment

Two Lithium technologies were investigated and compared: Lithium Iron Phosphate ($LiFePO_4$) and Lithium-Polymers.

The $LiFePO_4$ cell tested have a salt liquid electrolyte composed by $LiPF_6$. The active material of the anode is made of LiFePO4/C compound, while the active material of the cathode is made of graphite. Anode electrode conductor is copper, while for the cathode aluminum is used. The separator is made of organic carbonate. The housing of the present cell consists of polypropylene. The active material of the lithium iron-phosphate cell is located on the negative as well as on the positive electrode, in form of coatings. The active material of the anode is black lead powder as a coating on copper foil. Lithium iron-phosphate coating as layer on aluminum foil constitutes the active material on the cathode [32].

Li-Polymer cell tested is a pouch cell, with an electrolyte made with a solution of lithium hexafluorophosphate in a mixture of organic solvents EC (Ethylene Carbonate) + EMC (Methyl Ethyl Carbonate). The active material of the positive electrode is composed by $LiCoO_2$ and $LiMnNiCoO_2$ with a current collector consisting of an aluminium foil (15–20 mm). The active material of the negative electrode is made of graphite with a current collector made of copper (10–15 mm).

The cell specifications are shown in the Table 1.

The test equipment was chosen in relation to typology of tests and battery specifications. Power station has been realized with a Bitrode cycler able to supply and dissipate discharging 1.000 A with a rated voltage of 20 V. Current and cell voltage measurement were carried out via a current clamp and a voltage transformer, internal to Bitrode cycler. Power station was connected in parallel to each cell terminals and tests were controlled through a properly configured software (MTS PRO SW). Each cell was preliminarily

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