Methodology Development for Batteries Performances Analysis

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ABSTRACT

The necessity for storage is a response to economic, environmental, geopolitical and technological considerations. Technically and technologically, the actors of the energy sector produce energy and control the production devices without difficulty with well-defined margins. However, the entire scientific community is confronted with problems related to energy storage systems. Among the existing types of storage systems, electrochemical batteries seem adequate in developing countries. In order to optimize the energy efficiency of a small power plant based on renewable energy sources to meet human needs, this work highlights the analysis of electrochemical batteries by their intrinsic and extrinsic characteristics. For this purpose, the technical characteristics and materials of the components of existing batteries will be identified with their respective performance criteria. This analysis allows the identification of the most efficient type of battery with respect to the constitutive elements as well as their technical elements for the purpose of optimization in relation to the needs. This identification is carried out using an original methodological approach based on the "multicriteria decision matrix" or MDM. The developed approach could be used as a tool to help the energy optimization of production plants aiming at the energy transition.

Keywords: - *Electrochemical batteries, electrical energies, solar photovoltaic.*

1. INTRODUCTION

The production of electrical energy from renewable sources such as sun and wind is a solution for rural electrification in Madagascar. However, storage is still a major problem. It is important to choose a battery before using it, taking into account all the criteria related to its location.
The performance of a battery is a key criterion for choosing it. It is strongly dependent on the constituent elements (intrinsic criteria) and the technical characteristics (extrinsic criteria). An approach along these lines is developed in this work. The main objective is to develop a method for analyzing the performance of storage batteries.
First, materials and methods are given. The batteries in competition are showed. Then the Multi-criteria Matrix Decision (MDM) method is adopted. Assessment criteria using intrinsic and extrinsic criteria are presented and finally, results and discussions are showed.

2. MATERIALS AND METHODS

The materials and methods are the main contents of this section.

2.1 Materials

The materials used in this study are the battery technologies to be evaluated. In the framework of this work, the case of Madagascar is implemented regarding the type of batteries adapted.
Considering all analysis criteria and the real case of Madagascar, two types of batteries are put in competition:
- Lead acid batteries;

- Lithium-ion batteries.

Lead acid batteries are the most used in Madagascar while lithium-ion batteries seem to be the most efficient and recommended on the market today but are constrained by heat and temperature as Madagascar is a sunny island.

Table 1: Types of batteries to be evaluated

Battery types	Lead Acid	Lithium-Ion
Advantages	Low cost and robust	Energy density and robust power
Disadvantages	Low energy and sudden death	Safety ant cost

The performance of the constituent materials and the performance of the technical characteristics of each type of battery will be evaluated.

2.2 Methodological approach

There are several evaluation methods. To assess the performance of storage batteries, the approach adopted in this contribution is based on the "Multi-criteria Decision Matrix (MDM)". The MDM allows the evaluation of several options in situations where all possibilities seem plausible. The 5 steps of the MDM to be followed:

a. Identify the objective of the process and the type of decision;
b. List the possible solutions ;
c. Develop a list of criteria to be taken into account ;
d. Evaluate each solution against each of the criteria ;
e. Weight the judgments to identify the solution with the highest ratings.

For each criterion, a standardized score from 0.1 to 1 and in 9 intervals could be assigned to a given criterion. Then, a hierarchy of criteria according to the literature and the particularities of the modes of use in Madagascar is carried out. This consists of assigning weighting coefficients according to the importance of the criteria. The values can vary from 0.1 to 1.

2.3 Assessment criteria

a/ Intrinsic criteria

A battery is a reversible physical-chemical system that can convert chemical energy into electrical energy through redox reactions. Basically, a battery consists of:

- Cathode in which the reduction of metals takes place ;
- Anode which ensures the oxidation of the metals ;
- Electrolyte which impregnates the electrodes to allow the circulation of ions ;
- Separator which serves to avoid short-circuiting the battery as much as possible ;
- Current conductors.

Intrinsic criteria are the components of the batteries. The evaluation of these criteria is in relation to the performance of each material that makes up each cell.

Table 1 : Components and their respective materials of the batteries to be evaluated

	Battery types	
	Lithium-ion	Lead-Acid
Component cells	Materials	
Cathode	$LiCoO_2$	PbO_2
Anode	Graphite	Pb
Electrolyte	$LiPFe_6$	$2H_2SO_4$

Separator	PE	Glass fiber wool

b/ Extrinsic criteria

Extrinsic criteria are the technical characteristics of the batteries.

The criteria vary greatly depending on the needs and the desired levels of accuracy. All the extrinsic criteria identified are taken into consideration in the choice and basis of the MDM. Thus, the elements constituting the MDM are composed of the 16 extrinsic criteria, such as:

- Cost
- Power
- Capacity
- Lifetime
- Autonomy
- Recycling
- Reliability
- Mass density
- Performance
- Self-discharge
- Response time
- Discharge time
- Depth of discharge
- Density by volume
- Environmental impact
- Operating constraints

3. RESULTS AND DISCUSSION

3.1 Methodology developed

In order to apply the method, the five steps of the MDM have to be followed. With both types of evaluation criteria, two results have to be obtained. The weighting method is always the same:

$$Ponderation = Coefficient \times score \quad (1)$$

a/ Battery performance against extrinsic criteria

From the values of each criterion, they are classified by assigning scores corresponding to their values for each technology. For each criterion, a standardized score from 0.1 to 1 and in 9 intervals could be assigned to a given criterion. As an example, for mass densities of:

- 24Wh/kg ϵ [0; 25], the score is 0.1;
- 240Wh/kg ϵ [226; 250], the score is 1.

Next, a hierarchy of criteria according to the literature and the particularities of the modes of use in Madagascar is carried out. This consists of assigning weighting coefficients according to the importance of the criteria. On the basis of all the criteria established, in particular the scores attributed to the criteria as well as the weighting coefficients, both based on the MDM, the following figure illustrates the evolution of the cases of each technology according to the importance of the criteria concerning them.

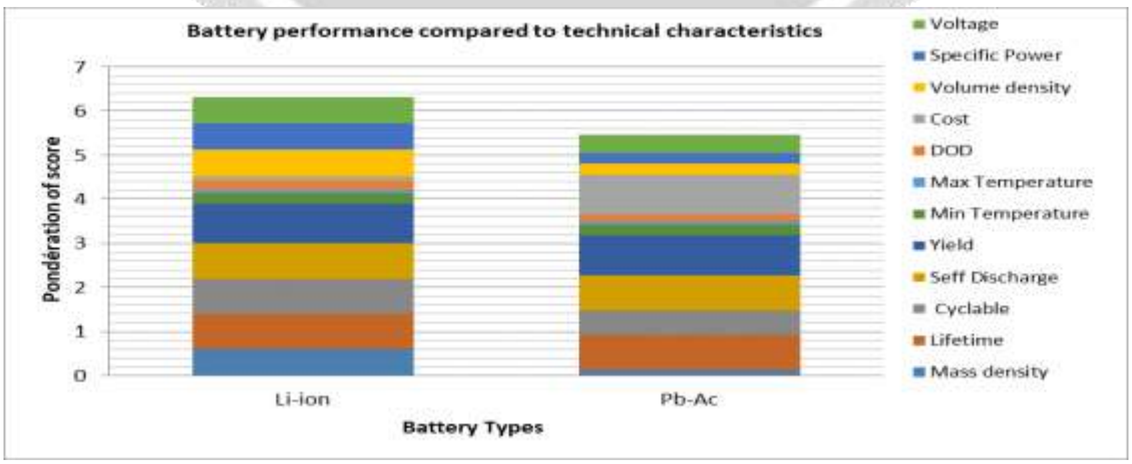

Fig. 1: Battery performance with extrinsic criteria (technical characteristics)

After a weighting (relation 1) of the scores with the assigned coefficients, the best performing battery is Lithium-ion than Lead Acid.

b/ Battery performance against intrinsic criteria

To determine the performance of a battery technology, formula (1) should be applied to any criteria for cathode, anode, and electrolyte and separator materials. Battery performance with respect to cathode, anode, electrolyte and separator:

$$\begin{cases} P_c = \sum_{i=j=1}^{nbc_c} Cc_i \times nc_j \\ P_a = \sum_{i=j=1}^{nbc_a} Ca_i \times na_j \\ P_e = \sum_{i=j=1}^{nbc_e} Ce_i \times ne_j \\ P_s = \sum_{i=j=1}^{nbc_s} Cs_i \times ns_j \end{cases} \quad (2)$$

With , $\boldsymbol{P_c}$: performance of the battery with respect to the cathode.
$\boldsymbol{P_a}$: performance of the battery with respect to the anode.
$\boldsymbol{P_e}$: performance of the battery with respect to the electrolyte.
$\boldsymbol{P_s}$: performance of the battery with respect to the separator.

With respect to the intrinsic criteria, the performance of the battery is defined by the sum of the performance of each component:

$$P_{battery} = \sum P_{c,a,e,s} = P_c + P_a + P_e + P_s \quad (3)$$

Here, $\boldsymbol{P_{battery}}$: Performance of the battery

The application of all the expressions of (2) gives the result shown in Figure 2.

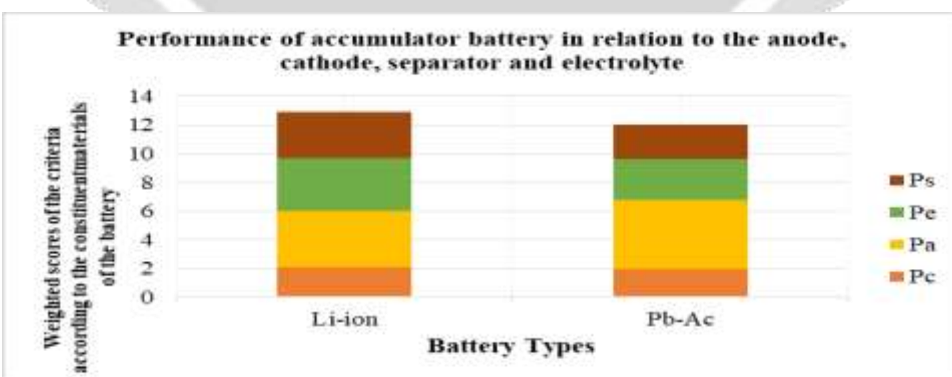

Fig.2 : Battery performance with intrinsic criteria (Ps, Pe, Pa, Pc)

c/ Battery performance against all criteria (CI and CE)

Based on the set of extrinsic and intrinsic criteria, both based on the MDM, the following relation (4) aggregates the battery performance:

$$P_{battery} = k_i.C_I + k_e.C_E \quad (4)$$

Battery performance related to intrinsic criteria (IC) and extrinsic criteria (EC) should be complementary. The k_i and k_e are coefficients assigned to weight the IC and EC scores.

Conditions:
ki > ke: for battery manufacturers.
ki < ke: for battery users.

Since the formula is already deduced, its application concerns the comparison of the most used battery technology (Lead Acid) in Madagascar and the most suitable technology (Lithium Ion) on the market. Lead-acid is robust, cheaper and less efficient than lithium-ion. Using the method developed, with **ke = 0.75** and **ki = 0.25**, lithium-ion is suitable for Madagascar, the lithium-ion type is efficient but more expensive than lead-acid.

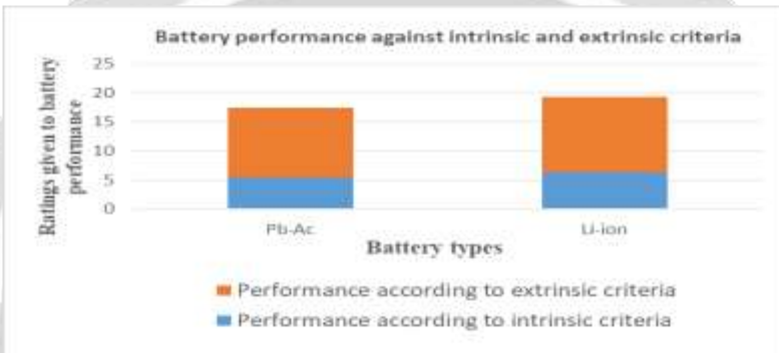

Fig. 3: Performance of lead acid and lithium ion batteries

According to the application results, between Li-ion and Pl-ac, the most efficient battery is the lithium-ion type. On the other hand, the Lead Acid battery is not unfavorable but its performance is inferior to that of Lithium Ion in some parameters.

4. CONCLUSION

The "Multi-Criteria Decision Matrix" method has made it possible to produce a methodology for analyzing the performance of storage batteries. This methodology consists in analyzing the technical characteristics (EC) and the constituent materials (CI). It is valid for both users and manufacturers of storage batteries.
Thus, compared to lead acid batteries, Lithium-ion types are the most efficient solutions.
The analysis allows the establishment of a database on the materials and technical characteristics of electrochemical batteries. This database will be used to further improve the performance of batteries to meet human needs in terms of energy on related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work

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