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COMPONENTS IN RENEWABLE ENERGY SYSTEMS WITH SIMILAR OPERATING CONDITIONS – CATEGORIES OF SIMILAR USAGE OF LEAD ACID BATTERIES

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ABSTRACT: The purpose of the work described here is the definition of benchmarking tests for lead acid batteries in renewable energy systems (RES). The operating conditions of components in RES, and in particular batteries, vary significantly. As a result, different test conditions have to be applied and making general recommendations for the selection and operation of batteries in a particular RES is a difficult task. Categories of RES are defined in that way that RES in the same category are subjected to similar operating conditions and a similar combination of stress factors acting on the battery. Specifying and testing components, providing benchmarking tests for selection and making recommendations for a product for a particular system can be made specifically for a particular category. This work is part of the EU Benchmarking project.

Keywords: 1 - RES; 2 – lead acid battery; 3 – operating conditions; 4 – ageing processes

1. Introduction

The categorization process was proposed and used in the Benchmarking project. The aim of the project is to help designers to better design and optimize Renewable Energy Systems (RES). The project results should also help users for better understanding their system and to indicate the main properties and evaluate the system performance. The project results will include test procedures and battery model that provides uniform test strategy for different RES systems.

The important part of the project is the categorization processed that is discussed in this paper. The process must determine categories of existing RES and define typical properties of the systems fitting into individual categories.

The practical results of the categorization process are supported by the fact that the process is based on real monitored RES from around the world.

2. Standard Evaluation Report

The measured data of a RES in the form of current, voltage and temperature time series were proceed by a software tool called THESA. The tool was developed to a web base application by Fraunhofer-Institute for Solar Energy Systems in Freiburg, Germany.

The THESA tool calculates the SOC of the battery and transforms the measured data and the input data describing the RES system into uniformed format called standard evaluation report (SER).

A single data set is considered a year period monitoring of a RES system.

2.1. SER output information

The output from the SER can be very briefly listed:

- RES description including the main components
- Graph of minimal and maximal battery voltage
- Graph of normalized current vs mean cell voltage
- Histogram of operation time vs SOC
- Graph of calculated SOC in year time period
- Histogram of operation time vs mean cell voltage
- Histogram of operation time vs norm. current
- Graph of Ah throughput in individual month
- Mean charge factor in individual month
- Histogram of operation time vs bat. temperature

The THESA tool output for a user is realized in a PDF file format.

3. The categorization strategy

It was proposed and decided to use stress factors for determination of the similar operating conditions with a respect to lead-acid batteries. The stress factors selected are the main parameters that influence the battery performance and the lifetime. Similar operating conditions means similar risk for a battery individual ageing mechanisms.

3.1 Ageing mechanisms

The main ageing mechanisms considered in the categorization process are:

- Grid corrosion
- Electrolyte stratification
- AM degradation (shedding, recrystallization, porosity and active surface change, and others)
- AM shedding
- AM hard/irreversible sulfation
- Water loss / drying out

The individual ageing mechanisms are very briefly described in that way that the operating parameters influencing the risks of particular ageing mechanisms are identified.

Grid corrosion

The corrosion process is particularly critical for the positive electrode current collector system. It may get mechanically too weak to hold the electrode and the corrosion layer may also significantly decrease electric conductivity of the current collector-PAM interface. The corrosion depends on the electrode polarization voltage, electrolyte gravity, temperature and on the grid alloy composition **[2], [3]**.

Electrolyte stratification

This is a vertical distribution of electrolyte gravity leading to the bottom electrode parts poor recharge and even to discharge by an equalizing current, to accelerated sulfation in that part and to other effects. The stratification is accelerated if the full recharge is done only seldom, if the cell is deep discharged and the current rate is very low.

AM degradation

AM degradation covers many complex processes in the PAM and NAM like PAM softening, recrystallization, active surface lost, porosity change, expanders and crystals modifiers destruction, preferential discharge and others, **[4]**,**[5]**. The AM degradation processes are usually accelerated when the battery is deep discharged and incompletely charged. Current rate and temperature also play a role, however their influence is more complex.

AM shedding

This is the process when AM particles are disintegrated from the electrode surface and may freely move in the battery depending on internal conditions. The shedding is accelerated by high rate gassing, high Ah throughput, high current rate and by fast temperature changes. Internal conditions in the battery like AM compression and obviously the AM composition play also a role.

AM hard/irreversible sulfation

It is the process when the AM is turned into lead sulfate without a possibility to recharge it back at a normal charge. The sulfation is accelerated by an incomplete recharge, a long stay at a low SOC and also a charge procedure plays a significant role. Temperature is also an important and more complex parameter.

Water loss/drying out

This is the process when water is being rapidly diminished from a battery due to extensive gassing. In a VRLA battery water can not be refilled and the process is called the drying out. An overcharge (charge parameters) and battery temperature are the main factors influencing the process.

3.2 Stress factors

Certain combination of the stress factors results in certain risk of individual ageing mechanisms. Six stress factors are considered in the categorization process. The number of stress factors is kept low to maintain a good overview of the categorization process, to have independent stress factors and to have a relatively clear view of the effect of factor combinations on ageing mechanisms. The categorization process is technology neutral; however at the moment lead acid batteries are practically the only technology used in RES. The individual stress factors selected in the categorization process are:

- Charge factor
- Ah throughput
- Highest discharge rate
- Time between full charge
- Time at low SOC
- Partial cycling

3.3 Stress factors intensity evaluation

An intensity level of individual stress factors must be evaluated in order to consider the influence of the stress factors on ageing mechanisms. A five level intensity index was selected:

1. Very low intensity
2. Low intensity
3. Medium intensity
4. High intensity
5. Very high intensity

The individual factor intensity level does NOT simply indicate a good or a wrong value. The combination of certain stress factors intensity may indicate an increased potential risk of certain ageing mechanism. If the particular ageing mechanism is performance limiting (life limiting), this obviously depends on the battery technology, design and quality.

Parameters for the stress factors intensity evaluation were determined on the basis of expert knowledge, and integrated within the Benchmarking categorization process into intensity criteria. The parameters were later proved such that the distribution of values measured in real existing RES systems corresponds with the expert created intensity criteria.

3.4 Description of individual stress factors

Charge factor

The stress factor is expressed by an average charge factor in a measured year period. The charge factor is defined as Ah charged / Ah discharged. In certain stress factors combination a high intensity of the charge factor (high charge factor) may lead to an overcharge resulting in the water loss/drying out; an extensive temperature rise; a high gassing; a thermal runaway; an increased corrosion; and an increased AM shedding. On the other hand lower intensity may lead to undercharge causing the hard/ irreversible sulfation and the electrolyte stratification.

Ah throughput

This factor is expressed by a year period cumulative Ah throughput (cumulative Ah discharge) normalized in units of nominal capacity. A high intensity (high Ah throughput) of the stress factor may influence the AM degradation, the AM shedding, and the electrolyte stratification.

Highest discharge rate

This factor is expressed by the highest current rate in which ≥1% of the Ah throughput was discharged. The current rate is expressed in the units of the nominal capacity. This parameter is used to indicate the power requirements to the battery. Concerning the ageing mechanisms a high intensity of the factor (a high discharge rate) may lead to less homogenous current distribution, higher battery temperature and thus higher water loss, preferential and incomplete discharge, and lower efficiency and on the other hand to better preservation of the original AM structure (crystals size, porosity) **[1]**, and reduced electrolyte stratification. The practical influence of the low discharge current rate that is mostly used in RES is not easy to clearly evaluate and to make a definitive statement.

Time between full charge

This factor is expressed by an average time in between recharge above 90% SOC. A high intensity of the stress factor (long time between full recharge) may influence the AM hard/irreversible sulfation and the electrolyte stratification. Lower intensity may be important for the corrosion, the water loss/drying out and the AM shedding.

Time at low SOC

This factor expresses time duration of a year in (%) in which the battery remained below 35% SOC. It represents also the battery rest time in below 35% SOC. A high intensity of the factor (long time duration) may influence the hard/irreversible sulfation.

Partial cycling factor

Cumulative Ah throughput in (%) is expressed in the following SOC ranges:

100 – 85 % : A
85 – 70 % : B
70 – 55 %: C
55 – 40 %: D
40 – 0 %: E

A single partial cycling factor is calculated by weighting function: PC=(A*1 + B*2 + C*3 + D*4 + E*5)/5
Higher factor intensity results from partial cycling at a low SOC level. A high intensity of the stress factor (low SOC partial cycling) may influence the AM hard/irreversible sulfation (particularly of the bottom electrode parts), the electrolyte stratification, and a preferential discharge leading to an accelerating ageing of certain AM fraction. On the other hand lower intensity may express shallow cycling (very mild discharge) and mostly operation as a standby fully charged battery.

4. Categories determination

The categories were derived from the stress factors intensity distribution at existing RES.

4.1 Visualization of the stress factors

The stress factors were visualized by the means of a radar plot. In a single radar plot the six intensity evaluated stress factors may be depicted. The individual stress factors in the radar plots were grouped in related areas, to allow easy visual comparison of RES system plots.

4.2 Categories derivation

A significant number of random selected data sets were depicted in radar plots and printed. The radar plot shapes were visually distributed only on the base of the resulting shape area appearance. Six categories were recognized and described by the individual stress factors intensity bands.

4.3 Description of the individual categories

The individual categories are described by their main properties and characteristic risks of the ageing mechanisms.

Category: G1

The radar plot of the category G1 with defined intensity bands of individual stress factors is shown on the picture **Fig. 1**. The allowed intensity band of each stress factor is marked by the dark color area. The typical operation of such of RES may be characterized as a full cyclic operation with battery deep discharge. The charge factor is low and the full recharge happens relatively seldom. The battery may also rest a long time in discharged state below. The battery operates often at partial SOC at relatively high discharge rate. The category is associated with a high risk of the hard/irreversible sulfation, the electrolyte stratification and the AM degradation. There is also a potential risk for a week cell reverse polarization at discharge.

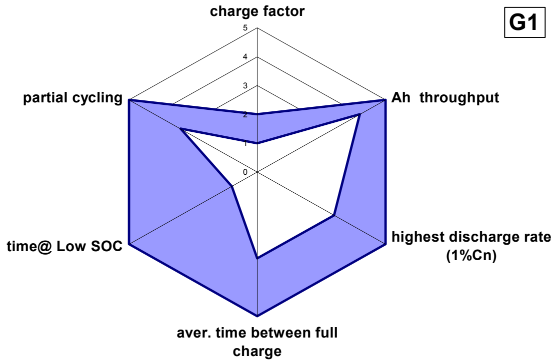

Fig. 1 Radar plot of the category: G1

Category: G2

The picture **Fig. 2** shows the radar plot of the category G2 with defined intensity bands of the individual stress factors.

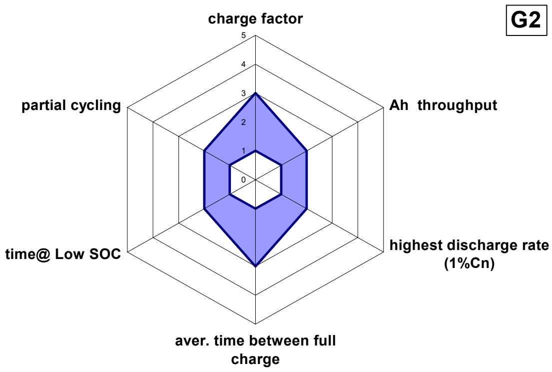

Fig. 2 Radar plot of the category: G2

The typical operation of such of RES may be characterized as a stand by or a very mild operation. The battery is only very seldom discharge and the battery is mostly kept at high SOC. The category is associated with a low risk of hard/irreversible sulfation, that may be mostly driven by the charge parameters. Also the risk of electrolyte stratification is low in the category. On the other hand there is a potential risk of corrosion.

Category: G3

The radar plot of the category G3 with is shown on the picture **Fig. 3**.

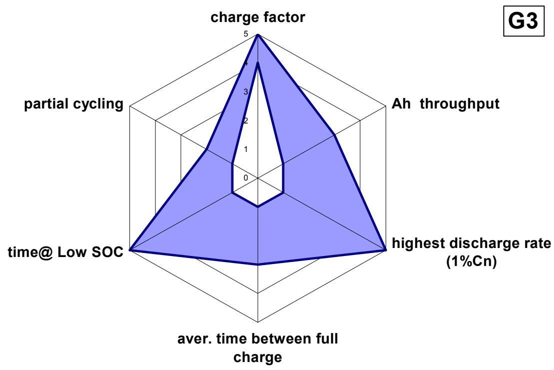

Fig. 3 Radar plot of the category: G3

The typical operation of such of RES may be characterized as a medium throughput operation. The battery is charged with very high charge factor and the full recharge happens usually very often. In certain cases the battery may stay for some time period at discharged state. The category is associated with a high risk of the corrosion, the water loss/drying out and the AM shedding. In a year period the battery may rest at rather low SOC conditions and thus there is an increased risk.of hard/irreversible sulfation.

Category: G4

The radar plot of the category G4 with defined intensity bands of individual stress factors is shown on the picture **Fig. 4**.

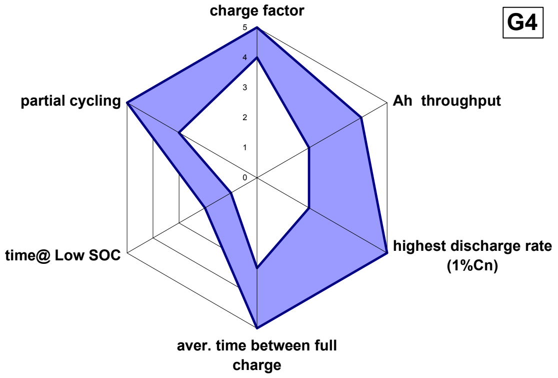

Fig. 4 Radar plot of the category: G4

The typical operation of such of RES may be characterized as a medium to a high throughput operation at partial SOC cycling with a long time between full recharge and a high charge factor. The battery usually does not stay for a long time at very low SOC. The discharge rate may be high immediately followed by some recharge that frequently does not bring the battery to 100%SOC. If the full charge is realized then the charge factor is too high. A high risk for the battery may be identified as the electrolyte stratification, the hard/irreversible sulfation and the AM degradation. There is also an increased risk of the water loss/drying out and the corrosion.

Category: G5

The picture **Fig. 5** shows the radar plot of the category G5 with defined intensity bands of the individual stress factors.

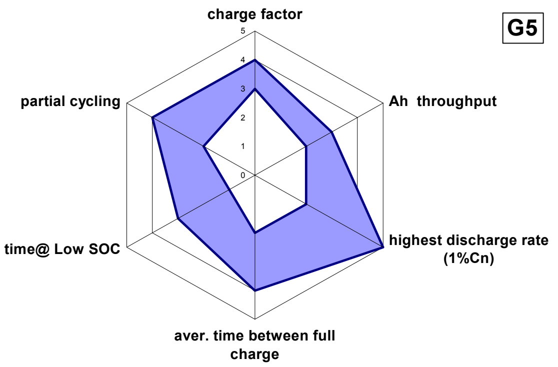

Fig. 5 Radar plot of the category: G5

The typical operation of such of RES may be characterized as a medium throughput operation at partial SOC cycling without a deep discharge or resting in a discharged state. The charge is realized by a medium charge factor. There is an increased risk of the hard/irreversible sulfation and the AM degradation. The RES system seems to be very well optimised.

Category: G6

The radar plot of the category G6 with defined intensity bands of individual attributes is shown on the picture **Fig. 6**. The typical operation of such of RES may be characterized as a medium throughput operation at a partial SOC cycling with a low charge factor. There may be some time period when the battery rest in a discharged state. A high risk may be indicated as the hard/irreversible sulfation and the AM degradation.

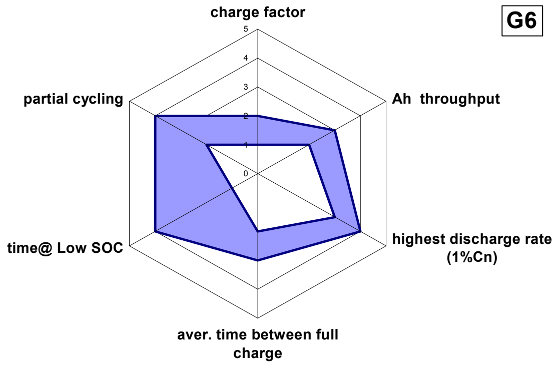

Fig. 6 Radar plot of the category: G6

5. Conclusions

The six described categories were derived from existing monitored RES systems around the world based on six stress factors. The intensity of the individual stress factors was evaluated on the base of expert knowledge integrated into intensity criteria. Finally the categories were derived from the visual appearance of the RES systems intensity evaluated stress factors depicted in the form of radar plots. In each category the stress factors intensity bands were specified and the categories were described.

In the Benchmarking project 95% of all available RES data sets fit to the specified categories. After the derivation of the categories the categorization may be done fully automatically. A simple software tool may be used to automatically classify a RES into the six categories.

In the further project work the test procedures for batteries and other RES components will be specified for the individual categories. A battery model will be created that may be run for an individual category and predict the system performance and lifetime. Recommendations for individual components and for an optimal design will be included in the Benchmarking project smart design tool.

Acknowledgment

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