Development of a general methodology on how to monitor and Benchmark renewable energy systems (RES), in particular energy storage systems.

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Abstract

Renewable energy systems (RES) are unique among energy supply systems because their performance and design depends entirely on the location and climatic conditions. A system optimised for an application in one location may be inadequate in another location even if the application and user requirements are identical.

The enormous variation between RES, which is the result of user requirements and local climatic conditions, makes it necessary to classify different installations into categories of similar use. Only installations belonging to the same category of use can be compared in a meaningful manner.

Energy storage systems, in particular battery systems, are crucial for the adequate performance of most RES systems. Batteries in a number of RES in Central Europe have been investigated using methods including calculations of the annual variation of state-of-charge (Sauer et. al., 1996) and their operating conditions have been grouped into four categories. It is obvious even using only this set of data that the operating conditions of batteries differ greatly. Without knowledge of the operating conditions it is difficult to select the most appropriate battery and compare systems performance.

This paper describes the ongoing development of a general methodology on how to benchmark RES and their components in terms of how to monitor RES and evaluate the data in such a way that the operating conditions and performance of individual components and the system as a whole can be analysed and compared. The methodology includes, but is not limited to, the following components described in the paper:

- Specification of requirements to measurement procedures
- Definition of standard evaluation reports
- Classification of systems into categories of similar use
- Standardised battery testing procedures and models for determination of battery operating life

The project will provide information on how RES and their components are currently used and this information will be utilised within the ongoing project Benchmarking[1)] to develop test procedures for benchmarking products. Users will be able to make better decisions based on test results and manufacturers will be able to focus their development better on requirements. The information obtained will help the industry in making better and more cost-effective products.

[1] „Benchmarking - Development of test procedures for benchmarking components in renewable energy systems applications, in particular energy storage systems". A project carried out by nine major European Research Centres, the Australian Cooperative Research Centre for Renewable Energy and the National Renewable Energy Laboratory in the USA. The project is supported by the EU under the 5th Framework Programme.

1. INTRODUCTION

Renewable energy systems (RES) are unique among technical energy supply systems because their performance and design depends entirely on the location and climatic conditions. A mismatch in RES components can make the system completely inoperable and a system optimized for an application in one location may be useless in another location even if the application is identical. This problem has been addressed by a number of organizations and has led to the development of planning software which takes the climatic conditions at the location of installation into account (Baring-Gould, 1996; Drouilhet, 1999; Manwell et al., 1999.

Batteries in a number of RES in Central Europe have been investigated (Sauer et. al., 1996) and their operating conditions grouped into four categories, which differ in energy throughput, average state of charge and yearly variation of state-of-charge etc. (Fig. 1). It is obvious from these data that different test procedures should be used to test the suitability of batteries for the different categories.

Fig 1: Characterisation of four different types of RES applications in Central Europe (Sauer et al., 1996)

	Category I	Category II	Category III	Category IV
Characteristics	- small currents - few cycles (mainly one yearly cycle)	- small currents - large number of partial cycles (at different states of charge)	- medium currents - large number of partial cycles (at good states of charge)	- high currents - deep cycles (0.5 to 1 full cylce per day)
Solar fraction	100 %	79 – 90 %	Ca. 50 %	< 50 %
Storage size for	| 10 days	3 – 5 days	1 – 3 days	approx. 1 day

Standard test procedures for lead acid batteries, the most widely used energy storage technology today, provide inadequate information on their suitability for a specific use in a renewable energy system. Test results such as the number of cycles achieved when there is unlimited power and time for charging or the lifetime of a battery under constant voltage charging conditions have little relevance for most RES applications. Recommendations and standards such as the Universal technical standards for solar home systems (1998); Procedures for determining the performance of stand-alone photovoltaic systems (1999), IEC 62124, IEC 61427 and IEC PAS 62111 are all useful for designing RES and sizing batteries but do not link test results published by battery manufacturers to the battery lifetime that can be expected in a particular location.

The correlation between operating conditions, operation strategies and expected lifetimes is highly non-linear for batteries and therefore specific test procedures for different operating conditions are necessary. A benchmarking process, which compares different battery technologies and products as to their suitability for a given use, requires accurate knowledge of the conditions of use (time series of energy throughput, state-of-charge, charging and discharging currents, etc.) and the relative importance of various test procedures in relation to each other - using lifetime prediction models and the criterion "lowest lifecycle cost".

The project described in this paper aims to develop and verify test procedures for benchmarking tests for energy storage systems. The project results will enable:

1. users to select the most suitable energy storage product for their specific application,
2. manufacturers to clearly define the category of RES for which their product is most suited and to estimate the expected lifetime for a well defined category of use.

Three issues have to be addressed to achieve the objectives of this project:

Necessity to define categories of "similar operating conditions"
The operating conditions of components are extremely variable. For instance the battery for a solar home system in Central Africa, a PV/hybrid system in Spain and a wind/hybrid system in Alaska, are

simply too different. Meaningful test procedures can only be defined for a clearly defined category of use.

Benchmarking process
Existing test procedures have to be evaluated for their relevance and, if necessary, new test procedures have to be developed. Test procedures can only be used for benchmarking if their results can be clearly linked to the intended use and the benchmarking criteria: meeting the performance requirements and achieving long life/low lifecycle costs.

Necessity to gain widespread consensus
The project needs to achieve a wide consensus; especially between the users and the manufacturers. All results have to be open and publicly accessible. The international business, industrial and scientific community is invited to contribute to the project and comment on the project results throughout this 36-month project.

2. PROJECT DESCRIPTION

The work plan for the project has four work packages:

- Work package one and two (WP1 & WP2) are necessary to define categories of renewable energy systems where the requirements for components are similar. These categories will not be component specific to avoid the creation of different, possibly overlapping or incompatible categories. However, it is believed that the different categories are mainly characterized by the different operating conditions of the energy storage system.
- Work package three (WP3) is the core of the project. Test procedures will be defined which simulate realistic operating conditions and performance requirements for each component and category.
- Work package four (WP4) will translate the proposed categories and test procedures into benchmarking procedures and recommendations concerning the selection of energy storage systems for planned renewable energy systems.

The following description of the work packages will explain the opportunity to participate and benefit from the project.

<u>WP1 Data on the operating conditions of components in renewable energy</u>
The first work package will create a publicly accessible database. It will use data on the operation and the performance of existing renewable energy systems and their components. The concept of "standard evaluation reports of the operating conditions" has been introduced. They summarize system performance data and can be compared easily. We presume that a full standard evaluation report for the most complex RES may contain up to 50 parameters and time series. It will include performance data of the system as well as measured and calculated time series of operation, e.g.

- Average wind speed, statistical wind fluctuations, time series of wind generation
- Time series of state-of-charge of energy storage system (this requires calculation from measured data because state-of-charge cannot be measured online)
- Load profile

The standard evaluation report is likely to have a practical use far beyond this project. If an analysis of the actual system performance is done at regular time intervals the report can be used to detect any faults in the system (like partial shading, improper operation of electronic components, unexpected energy consumption).

Fig. 2 shows schematically the assignment of existing data to the content of the future database: standard evaluation reports which make the comparison of systems and the process of classifying them possible.

Measured data (systems and components)	Verification process and analysis of data	Result: Standard evaluation reports of existing RES
Dataset 1	⇒	Report 1
Dataset 2	⇒	Report 2
Dataset N	⇒	Report N

Figure 2: Process flow chart for creating standard evaluation reports

All organizations worldwide are invited to provide data sets to the Fraunhofer Institute for evaluation. Confidentiality requirements will be respected. A standard evaluation report of the system will be provided in return and at the end of the project recommendations on sizing and choice of the most suitable energy storage technology will be given.

In addition to evaluating data sets it is necessary to evaluate reports on the performance of systems and components, lifetime anaylysis and investigation of failure modes, information on user behaviour and other information that has been collected by experts. We would appreciate receiving any such information.

WP2 Classification process and definition of categories

The standard evaluation reports will be used to define RES categories of similar operating conditions of all major components. The categories have to be universally applicable to gain the support of all relevant institutions worldwide for their use.

Fig. 3 shows how the large number of standard evaluation reports will be grouped together to form a small number of categories. From previous work we estimate that approx. 10 categories may be sufficient to describe all relevant RES ranging from a solar home system in Central Africa to a wind hybrid system in Alaska. A category is described by means of an exemplary standard evaluation report.

The description of the categories and the process of deriving them will be made fully available and presented to relevant international conferences. We intend to invite all those interested to comment on the categories so that the final description of the categories will meet the acceptance of all concerned.

Fraunhofer –Institute for Solar Energy Systems-ISE, Centre for Solar Energy and hydrogen Research (ZSW), the Institut für solare Energieversorgungstechnik ISET and WIP/Munich (Sauer et a., 1996) have defined categories in RES. They were based on the data of 24 RES installations in Central Europe. Fig.1 is a result from this project. In fact the concept and the general process that was applied then has been used for this project. Examples of possible categories are:

1. "Solar service". Small PV + battery. Very small capacity systems, e.g. bus shelter lights, car park ticket machines, sign lighting by professional users. Low energy throughput. Low winter insolation leads to extended periods of low state-of-charge and high summer insolation to extended periods of overcharging.
2. "Large solar installation with possibly commercial usage aspects". PV + battery + wind (in some cases) + backup generator. Solar fraction in the range of 50 %; high currents, significant daily energy throughput (0,5 - 1 times nominal capacity, professional operation

3. "Battery for smoothing". Wind + diesel + battery. The, battery is used to reduce the number of diesel start-ups, battery storage time ~ 30 minute or less with high discharge/charge rate and possibly very high energy throughput.

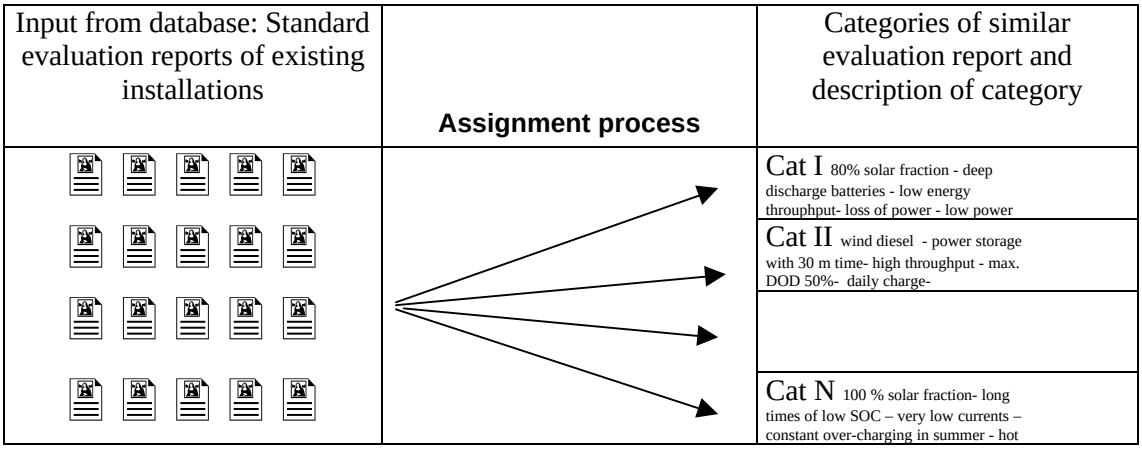

Fig 3: Process flow chart to show the process of forming categories. Mathematical tools to detect similarities between time series of a number of parameters will be used to assist the categorization process.

WP3 Definition of performance requirements and test procedures for benchmarking products:
The experience of the project partners shows, that the presently available test procedures are insufficient for a benchmarking process. Therefore, after evaluation of existing test procedures for which manufacturer's data are available, two different sets of additional tests will be defined:

→ Test procedures independent of the categories defined: These tests will characterise individual performance requirements not covered by standard tests until now.
→ One accelerated test procedure for each category: These tests will simulate the complex combination of performance requirements that exist.

Important performance requirements for energy storage systems in certain categories can be written technology neutral and may be, for instance,

- the turn-around efficiency during charging and discharging,
- lifetime expectations when excess energy has to be absorbed for a long time,
- the recovery time after prolonged periods of being in a low state-of-charge, or
- the effect of cycling at a partial state-of-charge.

Description of categories		Performance requirements		Test procedures (independent of category)
Cat I 80% solar fraction - deep discharge batteries - low energy throughput- loss of power - low power	⇒	Energy storage: - Ability to absorb excess energy - High charge efficiency - etc. Genset: - ..... Other components	⇒	Energy storage - lifetime during overcharging - Amount of energy stored in a given time under constant power charging - etc
Cat II wind diesel - power storage with 30 m time- high throughput - max. DOD 50%- daily charge-				
Cat N 100 % solar fraction- long times of low SOC – very los currents – constant over-charging in summer - hot				

Fig. 4: Process flow chart for linking categories, performance requirements and test procedures.

It is not the purpose of this work package to set standards in the formal sense, but to identify performance requirements and to define test procedures for the whole system and the components.

WP4 Benchmarking and recommendations as guidelines for planning

The results of different test procedures and their relative importance have to be matched to the requirements in the various categories so that a benchmarking process can be defined and recommendations can be made. The recommendations will advise on the most suitable products for each category, using overall lifetime cost as the main criterion.

The true importance of these recommendations and guidelines is that system implementers will be able to

- determine from existing simulation software which category their system will be most similar to
- use the recommendations on the specific componentry and technical data to select the most suitable product for each system.

The selection of equipment suited for particular operating conditions will not only reduce total system costs but also result in more reliable and consistent system design.

Fig. 5 shows the expected outcomes of the project: Recommendations based on weighted test procedures (criterion: lowest lifecycle cost) and an assignment of measured or simulated data to categories.

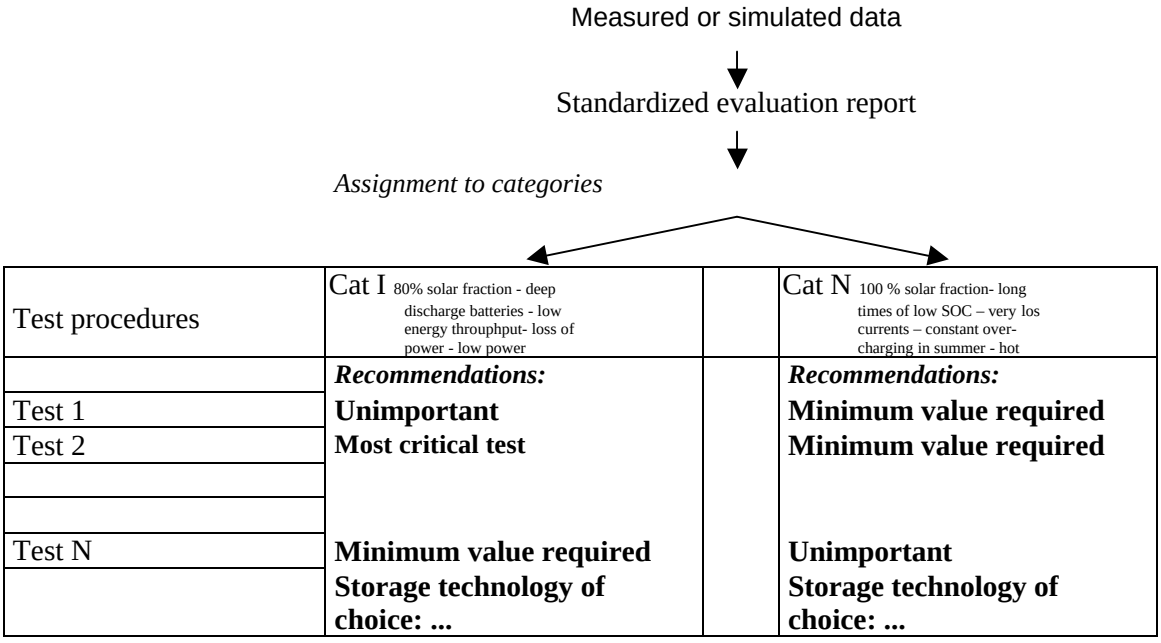

Fig. 5: Process flow chart showing the assignment of test procedures and their results to different categories of use.

Components, which score high marks for tests relevant to a specific category, can be considered to be particularly suitable for this category. For each category, the relative importance of the performance requirements will be assessed and absolute values concerning the results of tests suggested., cf. table 1 on the next page.

Widespread use of the project results and their adoption requires easy access to the results. Smart design assistant software will be developed which will be able to assign a category for each installation with a standard evaluation report ("classificator" software) and match the recommendations for test procedures and their relative weight to the installation under

investigation. A user of the database who submits data of a planned installation will automatically receive the information which category is most similar to the planned RES. He will also receive the recommendations made for the category. This software is planned as open access software.

Table 1: Example of test results for different categories of use

Performance characteristics / result of test procedure	Solar service	Large solar installation
Lifetime under float charging	Very important, should exceed ... years	Relatively unimportant
Cycle life	Unimportant	Very important, minimum 800 cycles at 80% DOD
Deep cyclability	Very important; It must be possible to recover the battery from a prolonged (e.g. 3 months) period of low state-of-charge within ...days.	Relevant
Self discharge rate	Important, better than ... %/month	Relatively unimportant

The main criterion for assessing test results is the lifetime cost of the energy storage system. Different products and technologies will achieve different test results. It is therefore necessary to simulate the lifetime costs of an energy storage system that will be used in a given category. Existing lLifetime prediction models will be developed further to achieve this:

3 Conclusions and Outlook

This project provides information on how RES and their components are currently used and this information is used within the ongoing BENCHMARKING project to develop test procedures for benchmarking products. Users will be able to make better decisions based on test results and manufacturers will be able to focus their development better on requirements. The information obtained will help the industry in making better and more cost-effective products.

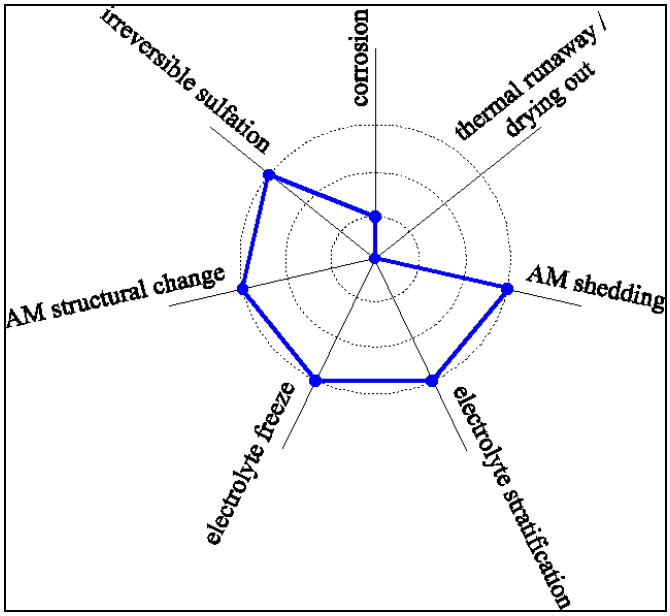

Fig. 1 Radar type chart for a photovoltaic system in a cold climate with a small storage system being frequently undercharged

All industrial companies will be able to benefit from the project results, which will be openly

accessible. Ultimately the project results have the potential of setting new rules. In a future mature market for components for renewable energy systems, a product should then be clearly labelled as being suitable for a certain category of RES and be able to prove its suitability with results from appropriate tests.

If you wish to use the data evaluation tool please contact the corresponding author to ask about the actual status and on the internet access link.

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