STANDARDISED EVALUATION OF RENEWABLE ENERGY SYSTEMS

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ABSTRACT

Renewable energy systems (RES) have to be designed specifically for both site and application. A comparison between different RES with the aim of evaluating the performance and the relative merits of the systems as a whole and/or their components is therefore difficult.

As part of the BENCHMARKING project which is an international project carried out by 10 European research organisations, NREL (US) and the Australian Co-operative Research Centre, a proposal is here presented on how to measure performance, compress data and evaluate them in a standardised form, i.e. a standard evaluation report (SER). It covers all types of renewable energy systems at any location and for any application. Its primary aim is to allow a comparison of RES and their key components.

1. INTRODUCTION

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. Comparing the performance of RES as a whole and their components is therefore difficult even if the application is similar. Furthermore, important data such as the power generated by a PV module or the current throughput of a battery are often measured at different points in the system (e.g. before or after the solar controller) using different time steps and averaging methods.

As part of the BENCHMARKING project a proposal is here presented on measuring procedures, acquiring data and evaluating RES in a standardised form, i.e. a standard evaluation report (SER). Its primary aim is to allow a comparison of RES and their key components.

Batteries in a number of RES in Central Europe have been investigated in the past using among other methods a calculation of the yearly variation of state-of-charge and their operating conditions. They have been grouped into four categories [1], [2]. Similarly, universally acceptable categories of RES with similar operating conditions can be defined using the SER and a process based on “indexed attributes”. This categorisation will also support further standardisation in the industry. An additional aim of the project is to make suggestions on how to select the most appropriate components for a given application that belongs to one of these categories.

Data acquisition systems (DAS) can demand a significant share of the total investment. It is therefore necessary to plan carefully what should be measured and how the data will be evaluated to meet the needs of the user, the system’s operator and/or system’s owner.

2. SPECIFICATION OF MINIMAL REQUIREMENTS OF MEASUREMENT PROCEDURES

To satisfy the needs of the monitoring process, five essential functions must be considered:

- Measurement of physical magnitudes that will indicate the system condition and operating status,
- Processing of the measurements to generate data displaying the installation condition and operating status as needed by the design methodology,
- Storage of data relevant to the system in an accessible format,
- Understanding and documenting the power system to address any data queries,
- Provision so that the monitoring system should continue to provide information on appropriate parameters even if the power system is not operating.

The position of the sensor in the circuit, the accuracy of the sensor, the averaging processes employed, etc. need to be considered in order to provide the maximum information possible within a given budget constraint. It is for instance recommended to calculate separate averages for the battery current, one giving the average current and Ah into the battery in a given period, the other giving the average current and Ah out of the battery in the same period. Without any additional hardware cost and negligible additional cost for data storage the real energy throughput of the battery can then be measured.

Three levels of data collection are suggested for system monitoring:

1. General performance monitoring to measure the output performance of the power system. This type of monitoring system would be used to ensure that the power system is operating, power is being supplied within proper parameters and that specific components are in fact operational.
2. System performance monitoring. It is similar to the above level but includes internal power system measurements. This level of monitoring can be used to assess component performance on a macro level and assist in trouble shooting of system components.

3. Scientific monitoring used to obtain an understanding of system operation and real time power flow. Data is also collected to monitor component efficiency and determine very specific operating performance.

Power measurements of items connected to the DC bus are completed by measuring the current between the DC bus and the device while taking simultaneous voltage measurement of the link. AC devices are measured through dedicated power (kVA or kW and Power Factor) measurement using transducers designed for these activities.

Due to the prevalence of distinct charge controllers or power conditioners between a specific component and the connection to other devices, i.e. the AC or DC bus, two parameters must be measured, one at the component and one at the specific bus. For example, the power flow before or after a charge control device in a PV system differs greatly. If such a device does not exist, the voltage at the component can be taken as the same as the voltage on the specific bus.

2.1 Signal Collection and Recording

Data collection can be broken down into two time intervals, the first is the measurement interval while the second is the storage interval. The measurement interval represents how often a sensor is used to record the value or condition it was designed to sense, such as voltage on the DC bus or wind speed. These measurements occur quite frequently and in most remote systems it would be impossible to record all of this information over a long period. To reduce the amount of data, measurements are usually processed to provide a meaningful average value over a longer time period, usually between minutes and days. This is the recording interval. It is important that the sample or measurement interval and the averageing method employed accurately captures the phenomena in question, such as AC ripple on a DC current. Collection accuracy will depend on the level and type of monitoring that will be required by the system or the desired results.

The level of system monitoring will dictate the requirements for the different time intervals for data storage.

3. STANDARD EVALUATION REPORT AND CLASSIFICATION OF SYSTEMS INTO CATEGORIES OF SIMILAR USE.

A comparison between different systems requires a data analysis in a standardised manner. Different terminology and different representations of the same data make it difficult, if not impossible, to compare data from different locations with potentially different applications. For this reason, a stringent, formalised manner of presenting data is suggested. Graphs, histograms and performance figures can then be used to identify categories of similar use of components, e.g. batteries, fuel operated generators or any other component in RES. Examples of possible categories with similar component sizes and overall energy throughput but completely different requirements are:

1. "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

2. "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.

A standard evaluation report may contain more than 10 time series, histograms and many more performance indicators. The task of matching data of a given installation to any other therefore represents a multidimensional vector analysis with weighted dimensions.

3.1 Performance Index

In order to be able to easily compare different RES systems and their components, it is important to produce normalised performance indicators. For batteries, the following definitions are made:

- The battery capacity is given at its 10 hourly rate C10.
- The battery voltage is normalised to the cell voltage, i.e. battery voltage divided by the number of cells in the battery pack.
- The charge and discharge current is normalised to the C10 rate of the battery.
- The relevant energy balances are normalised to the nominal power P_o, thus, resulting in final yields. (For the specific case of PV installations dividing the relevant energy balance by the total array area and total in-plane irradiance will result in overall efficiencies).

The above normalised energy throughputs will provide overall energy balances for the system. These energy balances include energy imported from an auxiliary generator (genset) or even energy exchange with the grid, and indicate the contribution that the RES generator (e.g. PV array) has made to the overall operation of the system.

The key parameters of interest which result from the system energy balance are:

1. Total input energy: it is the total input energy to the system coming from the RES generator, the genset (back-up generator), and the grid where applicable.
2. RES generator fraction: this corresponds to the energy supplied by the renewable generators to either the energy storage or the loads (i.e. surplus energy that can neither be stored or used and has to be dissipated is not included) as a percentage of total energy demand. (In a PV system, this is the solar fraction, i.e. energy supplied by solar energy as percentage of total energy demand.)
3. Energy drawn from the storage system.
4. Energy supplied to the storage system.

The mean values of these parameters over the reporting period give a good indication of the overall performance of RES systems, whether operating in stand-alone, hybrid generator or grid connected modes.

Furthermore, the determination of mean operating efficiencies for each component will be possible by using separate energy balance data over the reporting period for each of the different Balance of System (BOS) components calculated by summing the energy flow in and out of the components.

3.2 Visualisation of results: graphical presentation

Besides tables containing general information, climatic data, system balance and performance indexes as defined above, graphical representations in the form of plots are important to illustrate the operation of a RE system.

However, not all graphs are suited for proper presentation of data in a manner that is both easy to understand and serves specific purposes. The following graphs are included in the SER report:

1. A bar graph plotting the data availability in % for each month of the reporting period (one year) as well as for the year.
2. The normalised hourly mean PV array output power plotted in a scatter diagram versus hourly in-plane irradiance in kW/m2. This graph indicates how consistently the PV plant operates near to its maximum capacity. It also reveals any anomalous data points that should then be further investigated (see fig 1).

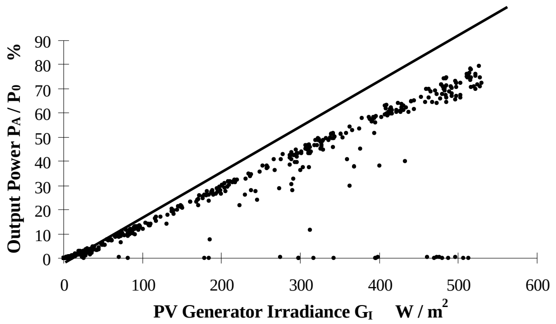

Fig. 1 Normalised ouptut power versus irradiance. The straight line indicates the optimal situation.

3. For each recording period the average wind turbine output power (kW) plotted in a scatter diagram versus the average wind speed (m/s) measured at hub height. This graph will indicate the effective power curve of the WT(s) determined by a binning of the data points using 1 m/s bin width.
4. A bar graph showing daily array and reference yields superimposed for each day of the month in case of monthly reports, or a bar graph showing monthly array and reference yields superimposed for each month in case of six-monthly or yearly summaries.
5. A similar bar chart as in point 4 is included for wind turbines. For wind turbines the relevant measurement is the measured power output and the corresponding efficiency based on measured wind speeds.
6. A bar graph representing the monthly average electricity generation and load for micro-hydro generators.
7. Graphs representing (see for instance fig. 2):
   - the maximum and minimum battery voltage per day (bar chart),
   - battery current [I10] versus mean cell voltage [V],
   - operation time in % of the year at a given SOC [%],
   - time series of the state of charge through the year,
   - operation time in % of the year at a given mean cell voltage [V],
   - operation time in % of the year at a given battery current in units of I10,
   - charged and discharged Ah in units of battery capacity per month,
   - charge factor in Ah and Wh per month,
   - operation time in % of the year at a given battery temperature.
8. Graphs representing inverter efficiency and energy throughput versus input power in units of inverter nominal power.
9. A bar chart representing the load consumption per day of the year.

The above information has to be either provided by the operator of the monitored RES plant or by the proper use of algorithms to extract them from the time series of the RES-plant monitored values. In particular the time series for the State of Charge of the batteries will be obtained by using the program for calculation of the state of charge (SOC) developed by Fraunhofer ISE [3].

The data evaluation tool is currently under development and will be available initially for the project partners. However it is planned within this year to make the tool available to the public. Simply by defining the systems and the data, the Internet tool will analyse the data and will provide the user with a standard evaluation report. This publicly available tool should become a standard for system analysis and assessment as well as for the benchmarking of components. As mentioned above only a commonly used and widely accepted procedure for the data analysis will assure a broad acceptance of the results obtained.

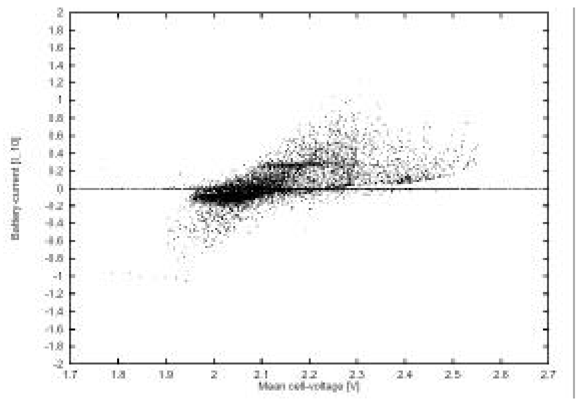

Fig. 2 Battery current [I_{10}] versus mean cell voltage [V]

4. CATEGORISATION PROCESS

The standard evaluation reports will be used to define RES categories of similar operating conditions. Different categories have distinctly different requirements and operating conditions for at least one major component. Batteries are the key component in RES determining the system life and performance; they also significantly influence the system cost. Therefore the categorisation process will be mainly controlled by the influence of battery ageing in RES.

Fig.3 attempts to show how a large number of standard evaluation reports would be grouped to form a few categories.

The categorisation process to be applied to the different RES applications is based on the so-called “attributes”. These attributes are the main ageing/degradation processes identified in lead acid batteries. These are corrosion, irreversible sulphation, active mass structural change, electrolyte stratification, active mass shedding, thermal runaway, extensive gassing and electrolyte freeze. The selection of these attributes is also connected to lifetime prediction models.

Input from database: Standard evaluation reports of existing installations	**Assignment process**	**Categories of similar evaluation report and description of category**
		Cat I 80% solar fraction - deep discharge batteries - low energy throughput- loss of power - low power
		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 low currents – constant over-charging in summer - hot

Fig. 3 Categorisation process

Risk indexes are assigned to these attributes (High risk, Medium risk, Minimal risk, No/Neglected risk) by means of parameters benchmarks. These parameters' benchmarks are created on the basis of experts' knowledge. The scheme Fig. 4 demonstrates the index assignment process to an attribute. In the first step the relevant parameters concerning the particular attribute will be selected from the SER In the second step the selected parameters will be evaluated by the means of the parameters' benchmark (experts' knowledge) and finally the four level index will be assigned to the attribute. This process will be performed to all attributes used in the categorisation. Later the assignment process can run fully automatically.

Then the "indexed attributes" are visualised allowing system class/category determination and fitting of the appropriate components (e.g. batteries) in a radar type chart. Fig. 5 depicts the visualisation of attributes for a particular example of RES system, i.e. a photovoltaic system with a small battery that is frequently undercharged in a cold climate.

5. CONCLUSIONS AND OUTLOOK

This paper provides information on how RES and their components are used. Within the ongoing BENCHMARKING project this information will be used 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 knowledge of how components are used will help the industry in making better and more cost-effective products.

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.

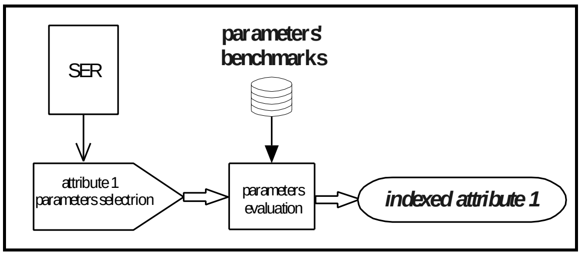

Fig. 4 Schematic demonstration of the index assignment to an attribute**.**

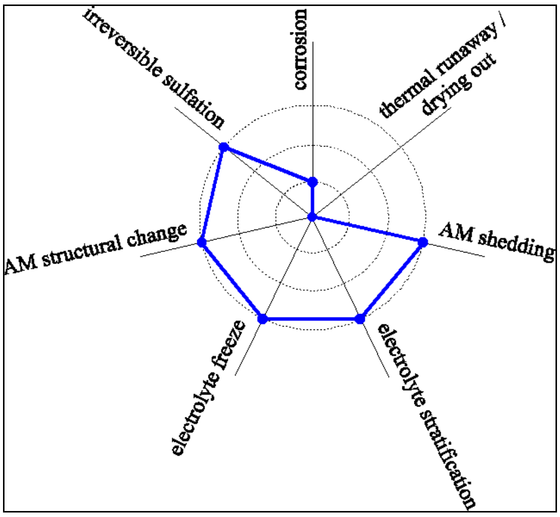

Fig. 5 Radar type chart for a photovoltaic system in a cold climate with a small storage system being frequently undercharged

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