Development of test procedures for benchmarking components in RES applications, in particular energy storage systems

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Specification of minimal requirement of measurement procedures

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I. Summary

Based on standards for the monitoring and evaluation of photovoltaic systems developed by both the International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronic Engineers, Inc (IEEE) this document is meant to be a baseline for data measurements for isolated power systems with all types of renewable based power generation. Systems incorporating one base technology or hybrid configurations of multiple technologies are likewise considered in addition to systems based around ac or dc power networks.

This specification describes in a comprehensive manner the measurements to be made by the data acquisition equipment installed in renewable based isolated power systems. It also indicates the information to be stored by the data acquisition system.

The minimum set of requirements for the data sets to be analysed as part of the Benchmarking project are identified as a subset of all possible parameters. The characteristics of this minimum data set are also described. The Benchmarking project will use the data primarily to identify categories of similar use of components, with specific attention to the energy storage systems, and as such will require only specific information that may not be required for other purposes.

II. Introduction

The reasons for monitoring the operation of power systems are as varied as the power systems that could be monitored. However, there are some common threads that this document brings together to allow a balanced approach to monitoring activities. This document was designed to be as inclusive as possible, proposing a framework that describes the monitoring of most types of off grid power systems. However, the authors are under no elusion that it is truly all inclusive. The reasoning for the production of this document rests in the fact that no general specifications has yet been produced. There have been a number of documents written which standardize the measurement of power systems, but these have all been technology or applications specific, such as standards for monitoring solar home systems. However, these standards can be quite restrictive and are not applicable in defining the measurement systems using different components or design philosophies. Because the Benchmarking project requires that data be collected from a broad range of power system architectures it was not possible to use existing technology specific specifications, thus leading to this document. Where possible already accepted international standards were used in the development of this document.

The document identifies a large number of specific parameters that can be measured as part of an off grid power system monitor and provides specifics about how these parameters should be measured and tabulated. This document then suggests three levels of monitoring that may be appropriate for different desired outcomes.

Although the authors have tried to provide the most relevant information, the experience that this report encompasses is by no sense complete. It is based on years of field work in hybrid power system design and monitoring but with the clear understanding that the technology is still evolving.

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 documentation of the power system to address any data concerns
- Provision so that the monitoring system should continue to provide information on appropriate parameters even if the power system is not operating.

In conclusion, this document recommends specific parameters, provides information of data collection intervals and collection frequencies. However, this document is not a guide to the monitoring of remote power systems. It is recommended that anybody interested in the area of power systems monitoring should obtain a basic understanding of measurement theory before attempting to monitor remote power systems.

III. Specification of Data Collection Requirements

The Benchmarking Project funded by the European Commission and its member states in cooperation with the governments of Australia and the United States of America will consider data collected from a wide variety of hybrid power systems in order to obtain a specific system operational classification of the different system components. To this end a minimum set of data to be used in the classification process was required. This following section specifies the type of data that should be collected from the power system and concludes with the minimum data records that will be needed for the classification work being conducted specific to the EU Benchmarking project.

III.1 Parameters to be Determined

Two types of small power systems dominate use, the most common has the predominate connections of each device to the dc bus, figure 1. The second type has each device connected to the ac bus, usually through a dedicated power converter or signal conditioner, figure 2. These figures represent systems in accordance with

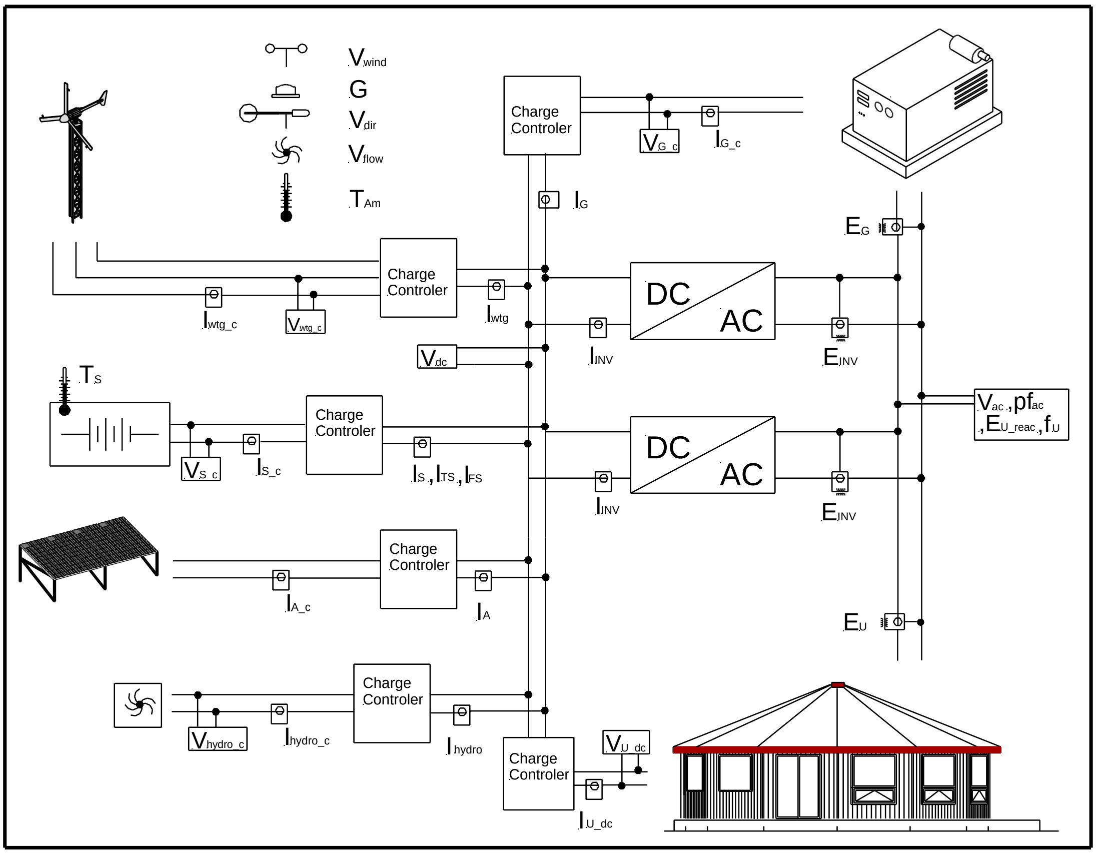

Figure 1: dc based power system

hybrid specification IEC-62257-1 (Draft) T_2, T_3, and T_4. 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, KW and/or Power Factor) measurement using transducers designed for these activities. In cases where more than one component of the same type is included within the power system, such as two strings of batteries or two power converters, the measurements can either be taken independently or as a summation of the two components.

Due to the prevalence of distinct charge controllers or signal conditioners between a specific component and the connection to other devices, i.e. ac or dc bus, two parameters must be measured, one at the component and one at the specific bus. The specification “c” is used to identify a measurement on the component side of any signal conditional or voltage control device. If such a device does not exist, or is not to be considered, these measurements do not need to be considered and the voltage at the component can be considered the same as the voltage on the specific bus.

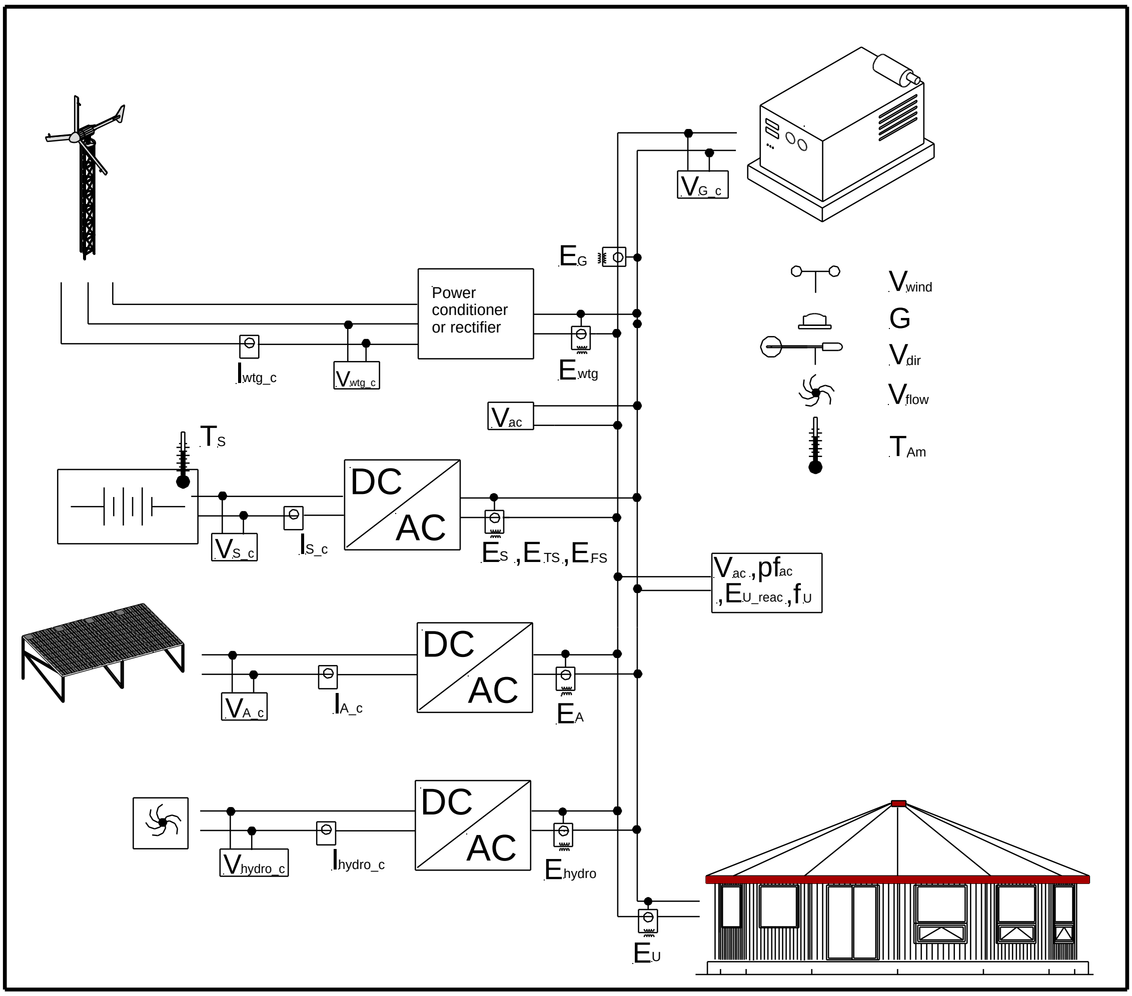

Figure 2: ac based power system

III.1.1 dc based measurements

I_S : battery current going into and out of the battery storage from the dc or ac bus. If the system includes a voltage controller, signal conditioner or other device located between the battery and the specific bus, I_{s_c}, should also be measured to determine the actual current into the battery storage. I_s can be measured as either a total or per battery string.

I_{TS}: battery current to storage, measured or calculated separately from the battery current measurement.

I_{FS}: battery current from storage, measured or calculated separately from the battery current measurement.

I_{s_c} : battery current at the battery terminals in the case of a system with a separate battery charge regulator or signal conditioner between the battery and electrical bus. Measurement can be completed as either a total or per battery string.

I_{wtg}: current from wind turbine generator between the charge controller and the dc bus. May be total for all wind turbines or individually. Measured at the voltage of the dc bus. Voltage is assumed to be the same as the dc bus bar.

I_{wtg_c}: current from wind turbine generator before the wind turbine charge regulator. May be total for all wind turbines or individually though in most cases each turbine uses an independent charge controller.

I_A: current from a PV charge controller to the dc-Bus. May be total for all PV controllers or individually if more than one is used. Voltage is assumed to be the same as the dc bus bar.

I_{A_c}: current from PV modules before the charge controller or maximum power point tracker. May be total for all PV array modules or individually.

I_{hydro}: current from a dc based micro hydro turbine. May be total for all units or measured individually. Voltage is assumed to be the same as the dc bus bar.

I_{hydro_c}: current from a single micro hydro unit before any charge regulator or power converter. May be total for all units or individually.

I_G : current output of the backup generator set if the generator provides energy directly to the dc bus. May be total for all units or individually. Voltage is assumed to be the same as the dc bus bar.

I_{G_c} : current output from a single backup generator set before any charge regulator or power converter. May be a total for all units or measured individually.

I_{U_dc} : current to the loads or applications that are supplied with dc power. This current is measured at the boundary of the production system and the distribution or application.

I_{Inv} : current to or from the inverter on the dc side of the converter.

V_{dc} : voltage at the terminals of the dc bus. In the case of most small systems this is the same as the voltage at the battery bank but if a dedicated battery charge regulator is installed between the dc junction box and the battery, this value may be different.

V_{s_c} : voltage measured across the terminals of the battery in a system including a dedicated voltage controller or charge regulator between the battery and the central bus of the power system.

V_{wtg_c} : Voltage of the line between wind turbine and turbine charge controller. If there is no charge controller this voltage will be the same as the dc bus voltage V_{dc}.

V_{A_c} : Voltage of line between PV array and charge controller. If there is no charge controller this voltage will be the same as the dc bus voltage V_{dc}.

V_{hydro_c} : voltage at the terminals of the hydro turbine if different from the connection bus. Output of the turbines will depend on the designed system but could be either ac or dc.

V_{G_c} : dc voltage across the terminals of the generator set prior to a regulated voltage controller. Output of the generator will depend on the designed system but could be either ac or dc.

V_{U_dc} : supply voltage of the dc application point. In most cases this will be equal to the dc bus voltage, V_{dc}.

Since voltage drop can be a problem when low voltage dc devices are connected over long power cables, care should be taken in the location of dc voltage measurements. The reason for the measurement should be the key to the identification of the measurement point. If performance of a specific component is of interest, voltage should be measured at the component. If performance of a specific system is of interest then the measurement should be taken at the point where the dc device is connected to the power system, i.e. at the power system end of the power cables.

III.1.2 Environmental measurements

G : Solar irradiance on a surface horizontal to the earths surface, W/m^2
G_I : Solar irradiance incident on the PV panel of the system being measured, W/m^2
V_{wind} : Wind velocity at a specified height (m/s). May be multiple measurements. For wind systems these values should be at the height of the wind turbine or correlated to that height. It is also recommended that wind speeds at different heights be measured. For PV systems, the measurement should represent air flow over the PV array.
V_{Dir} : Direction of the wind at the same location as velocity measurement. (degrees)
T_S : battery temperature. (C). This should be mounted at the negative battery terminal, next to a temperature-compensation sensor, if applicable, submerged in the liquid of a battery cell or on the cell wall. Temperature may also be recorded at the charge controller although this should be noted.
T_{Am} : Ambient temperature (C). Sensor should be enclosed in an appropriate ventilated radiation shield mounted in a location that will indicate the environment in which the system is operating.
V_{flow} : Volumetric flow rate of the water in stream, m^3/s, in close proximity to the hydro turbines.

III.1.3 ac Based Measurements

ac power measurements require an understanding of the characteristics of the power being measured. If the parameters are being calculated from dc current and voltage measurements, the result is total power, VA. Generally all measurements of power should be of VA to coincide with dc power measurements. If the power factor is going to be less that 1, ac power measurements should allow the calculation of the real and reactive power. This will require that two of the following four measurements be made. Real power (Watt), total power (VA), Reactive power (Var) or power factor. This is specifically true for any measurements of system load as most will not have unity power factor. dc power should be calculated from voltage and current measurements. Power measurement should include the losses associated with any charge controller or power conversion device.

E_S : Quantity of energy placed into or taken out of the battery (E_{TS} and E_{FS}).

E_G : Energy from the generator set.

E_{wtg}: Energy produced by the wind turbine generator arriving at the ac or dc bus. May be a total for all wind turbines or individually.

E_A: Energy produced by the PV array. May be total for all PV modules or individually.

E_{hydro} : Energy produced by the micro hydro turbine. May be total for all hydro units or individually.

E_U : Energy supplied to loads(dc and/or ac), measured at the connection to the power system ac or dc bus terminals.

f_U : Frequency of the power being supplied to the power system.

V_{ac} : Voltage of the ac bus.

pf_{AC} : Power factor of power on the ac bus.

E_{U_reac} : Reactive power requirements on the ac bus

III.1.4 Calculated or determined measurements

E_{REN} : Energy produced by the renewable energy sources. Can be measured, calculated from voltage and current measurements of each renewable energy device, or by summing the power from each renewable energy device. Assumed to be the actual available energy provided by the generators either to the dc or ac bus and would include any losses associated with a dedicated charge controller for each piece of equipment. Measurements need to be taken between the generator and any dedicated charge controllers.

I_{REN} : total current put out by REN sources (PV generator, wind-powered generator etc). May be a measurement of all of the renewable devices or a summation of measurements of all other renewable devices. Measurements need to be taken between the generator and any dedicated charge controllers.

t_G : generator set running time. Usually measured by tracking the voltage of the generator and summing the number of samples per time period that voltage is present. This will provide the running time per sample period.

S_{SOC} : The state of charge of the battery bank. Usually calculated by summing up the currents into and out of the battery over each time step and estimating from voltage and temperature measurements the proportion of the charging current which leads to gas evolution. SOC calculation requires periodic resetting when conditions of full charge have been met. This parameter can be measured/calculated with specific devices, but due to the cost and complexity of these devices, it is rarely done.

E_{Th} : The theoretical energy that could be produced by all of the renewable energy devices based on the REN resources present at the site assuming no regulation by the generation devices (PV, wind-power, micro-hydro or renewable based generator). This is the energy that the installation would have been capable of producing if there had not been low demand when energy was available and, at the same time, the regulating system had not limited or stopped charging the batteries due to high voltage as they became fully charged.

III.1.5 Sign convention for signals

Sign convention is a significant issue for the measurement of power systems. Generally published international standards have a very narrow focus of how this should be determined, usually focused on the battery as the determining point for energy nomenclature. However, it is recommended that an electrical engineering sign convention using the approach of nodal analysis be adopted. Using this convention, the central connection point or node of a power system is either the ac or dc bus. Energy or current flowing into the node is considered positive while energy or current flowing out of the node is considered negative. In this case, energy or current going into the battery, away from the dc or ac bus, is negative, energy coming out of the battery, and into the dc or ac bus, is positive. Energy or current going into the loads is negative while energy generated from the renewables is positive. This allows a clear view of energy flow in the power system.

III.1.6 Type of desirable measurements

Table 1 shows the type of desirable measurements depending on the configuration of the power system under consideration. In addition, all environmental measurements (see III.1.2) are taken.

Table 1: Measurement depending on system type		**dc Bus Centred Power Systems**		**ac Bus Centred Power Systems**	
		Measured	Calculated	Measured	Calculated
V_{dc}	Voltage on dc bus	●			
V_{S_c}	Voltage at battery terminals if different from V_{dc}	●		●	
I_S	Battery current (and direction I_{TS} and I_{FS})	●			
I_{S_c}	Battery current (and direction) before charge controller	●		●	
I_{REN}	Summation of RE sources current		●		
I_{wtg}	Wind turbine current after controller	●			
I_{wtg_c}	Wind turbine current before controller	●		●	
V_{wtg_c}	Wind turbine voltage before controller	●		●	
I_A	PV current from the charge controller	●			
I_{A_c}	PV current from the module/module	●		●	
V_{A_c}	PV voltage from the module/module	●		●	
I_{hydro}	Micro hydro current	●			
I_{hydro_c}	Micro hydro current from specific module	●		●	
V_{hydro_c}	Micro hydro voltage (if different from V_{dc} or V_{ac})	●		●	
I_{Inv}	Inverter current from dc bus	●			
I_G	Generator set current	●			
I_{G_c}	Generator set current from specific module	●		●	
V_{G_c}	Generator set voltage (if different from V_{ac})	●			
I_{U_dc}	Current at the dc utility input (if any)	●			
V_{ac}	Voltage of ac bus	●		●	
E_S	Energy into/out of battery bank		●	●	
S_{SOC}	Battery State of Charge		●		●
E_{REN}	Energy from REN sources		●	●	
E_{wtg}	Energy from wind turbine(s)		●	●	
E_A	Energy from PV array(s)		●	●	
E_{hydro}	Energy from micro hydro turbine(s)		●	●	
E_{Th}	Theoretical Energy from REN sources		●	●	
E_G	Energy from generator set		●	●	
E_U	Energy supplied to loads	ac Loads	dc Loads	●	
pf_{AC} or E_{U_reac}	Applications power factor or reactive power requirements.	●		●	
f_U	Applications supply Frequency for ac	●		●	
	Diesel Operational Status (On or Off)	●		●	
t_G	Generator set running time		●		●
	Fossil Fuel Consumption – may be taken from site logs	●		●	

III.2 Levels of Performance Monitoring

Three levels of data collection are seen as common in system monitoring.

General performance monitoring:
Measures the output performance of the power system. Based mainly on system inputs and outputs, not on the internal working 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. This level of system monitoring will not provide much assistance in system troubleshooting or even to determine if specific components are operating in accordance with designed specification.

System performance monitoring:
Similar to the above level but includes internal power system measurements. This level of system monitoring includes dc system voltages and currents or ac power measurements internal to the power system and allows for a general understanding of energy flow within the power system. This level of monitoring can be used to assess component performance on a macro level and assist in trouble shooting of system components. System design can also be assessed as well as the efficiencies of specific components.

Scientific monitoring:
This level of measurement will be used for scientific purposes in order 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. Data may be collected at a high frequency but will gather very quickly and so is not applicable for occasional analysis of general operational parameters. This level of monitoring should be used in order to allow very detailed analysis of system parameters and components.

Table 2 provides a specific list of the data that should be collected depending on the level of system oversight that is desired.

Table 2: Parameters to be provided		Type of data to be collected		
		General Performance	System performance	Scientific
V_{dc}	Voltage on dc bus	(●)	●	●
I_S	Battery current (and direction)		●	●
I_{S_c}	Battery current (and direction) before charge controller			●
V_{S_c}	Voltage at battery terminals (if different from V_{dc})		●	●
I_{REN}	Summation of RE sources current	(●)	(●)	
I_{wtg}	Wind turbine current after controller		(●)	●
I_{wtg_c}	Wind turbine current before controller			(●)
V_{wtg_c}	Wind turbine voltage before controller			(●)
I_{A_c}	PV current from the module			(●)
I_A	PV current from the charge controller		(●)	●
V_{A_c}	PV voltage from the module			(●)
I_{hydro}	Micro hydro current		(●)	●
I_{hydro_c}	Micro hydro current from specific module		(●)	(●)
V_{hydro}	Micro hydro voltage (if different from V_S or V_U)		(●)	●
I_{inv}	Inverter current from dc bus		●	●
I_G	Generator set current	(●)	●	●
I_{G_c}	Generator set current from specific module	(●)	●	●
V_G	Generator set voltage (if different from V_{ac})	(●)	●	●
V_{G_c}	Generator set voltage before converter		(●)	●
V_{U_dc}	Voltage at the dc utility input (if any)	●	●	●
I_{U_dc}	Current at the dc utility input (if any)	●	●	●
V_{ac}	Voltage at the ac utility input (if any)	●	●	●
pf_{AC} or E_{U_reac}	Applications power factor or reactive power requirements.	(●)	(●)	●
E_S	Energy into/out of the battery bank		(●)	●
E_{REN}	Energy from REN sources	(●)	●	
E_{wtg}	Energy from wind turbine(s)		(●)	●
E_A	Energy from PV array(s)		(●)	●
E_{hydro}	Energy from micro hydro turbine(s)		(●)	●
E_{Th}	Theoretical Energy from REN sources		(●)	●
E_G	Energy from generator set	(●)	●	●
E_U	Energy supplied to loads (dc and/or ac)	●	●	●
f_U	Applications supply Frequency for ac	(●)	(●)	●
Atmospheric measurements				
G_I	Solar irradiance on array surface (may be more than one)	(●)	●	●
G	Solar irradiance on a horizontal surface		(●)	●
V_{Dir}	Wind Direction at site (may be more than one)		●	●
V_{Wind}	Wind Speed at site (may be more than one)	(●)	●	●
T_S	Battery temperature		(●)	●
T_{am}	Ambient temperature	(●)	●	●
V_{flow}	Water flow meter (may be more than one)	(●)	●	●
Determined or calculated Parameters				
	Diesel Operational Status (On or Off)		(●)	●
t_G	Generator set running time	●	●	●
	Fossil Fuel Consumption – may be taken from site logs	(●)	●	●
● : mandatory information, (●) : optional information				

III.3 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 value over a longer time period, usually between minutes and days. This is the record interval. The measurements are being continuously made and forgotten, but the important information is recorded in the data logger memory for future use.

The following two sections provide information on both the collection and processing of information in monitoring systems.

III.3.1 Sensor measurement interval

The sensor measurements account for the majority of data collection complexity. Initially it is important to understand the dynamics of the signals being measured to insure that the information being collected is valid, meaning that it represents the phenomenon being measured. Numerous pages of text apply to this issue but it is important that the sample or measurement interval accurately captures the phenomena in questions, such as ac ripple on a dc current. Table 3 provides basic data collection parameters such as the frequency of collection and general information specific to the collection of such data. Collection accuracy will depend on the level and type of monitoring that will be required by the system or the desired results. More detailed information is provided in the annex of this document in the for each type of measurement described.

Table 3: Parameter Specific Measurements			**Measurement specifics**		
	Information to be provided	**Annex**	**Frequency**	**Processing**	**Minimum Accuracy**
V	dc voltage measurements	A1	1 or .1 Hz	Average	1.0%
I	dc current measurements	A2	20 Hz	Important issue - depends on specific parameter	1.0%
V_G	Generator set voltage	A3	1 or .1 Hz	Average	1.0%
V_{ac}	Voltage at the utility input (ac)	A3	1 or .1 Hz	Average	1.0%
E_{ac}	All ac power measurements	A4	Depends	Summation	2.0%
PF_{AC}	Applications power factor	A4	1 or .1 Hz RMS	Average	1.0%
RW_U	Applications reactive power requirements.	A4	1 or .1 Hz RMS	Average	2.0%
f_U	Applications supply Frequency for ac	A3	1 or .1 Hz	Average	1.0%

Atmospheric measurements					
G_I	Solar irradiance on array surface (may be more than one)	A5	1 or .1 Hz	Average	5%
G	Solar irradiance on a horizontal surface	A5	1 or .1 Hz	Average	5%
V_{Dir}	Wind Direction at site (may be more than one)	A6	1 or .1 Hz	Average	Sector
V_{Wind}	Wind Speed at site (may be more than one)	A6	1 or .1 Hz	Avg, max, min	1 m/s
T_S	Battery temperature	A7	1 or .1 Hz	Average	1 %
T_{am}	Ambient temperature	A7	1 or .1 Hz	Average	1 %
V_{flow}	Water flow meter (may be more than one)		1 or .1 Hz	Average	?
Determined or calculated Parameters					
	Diesel Operational Status (On or Off)	A8	1 or .1 Hz	Op flag	
t_G	Generator set running time		1 or .1 Hz	Summation	
S_{SOC}	Battery state of charge		1 or .1 Hz	Average %	
	Fossil Fuel Consumption – may be taken from site logs			Summation	

III.3.2 Data Recording Interval

The level of system monitoring will dictate the requirements for the different time intervals for data storage. Basic data collection should be based on sample rates as described in Table 4 and either summed or averaged as specified. Due to the different uses of the data, data storage should be conducted at different gradations.

General performance monitoring: Generally measurements are assumed to be stored at intervals and with the proper parameters to outline basic system operation. In many cases daily averages of operational totals are enough to provide accurate assessment of system operation. Data for performance monitoring is typically stored as daily summary values with maximum and/or minimum values as needed.

System performance monitoring: Due to the number of parameters being measured and the length of time of system operation, hourly averaged or summed parameters will be sufficient to allow monitoring of the system performance and assessment of the operation of different components.

Scientific monitoring: Data collection and storage rates will depend on the level of testing to be conducted. In many cases data is stored every minute.

Table 4: Storage Interval		Type of data to be collected		
		General Performance	**System performance**	**Scientific**
I_{dc}	dc current measurements	Daily	Hour	Minute
V_{dc}	dc voltage measurements	Daily	Hour	Minute
I_G	Generator set current	Daily	Hour	Minute
V_G	Generator set voltage	Daily	Hour	Minute
I_U	Current at the utility input	Daily	Hour	Minute
V_{ac}	Voltage at the utility input	Daily	Hour	Minute
pf_{AC} or $E_{U\ reac}$	Applications power factor or reactive power requirements.	Daily	Hour	Minute
f_U	Applications supply Frequency for ac	Daily	Hour	Minute
Environmental Measurements				
G_I	Solar Radiation on array surface	Hour	Hour	Minute
G	Solar irradiance on a horizontal surface		Hour	Minute
V_{Dir}	Wind Direction at site		Hour	Minute
V_{Wind}	Wind Speed at site	Hour	Hour	Minute
T_S	Battery temperature		Hour	Minute
T_{am}	Ambient temperature	Hour	Hour	Minute
V_{flow}	Water flow meter	Hour	Hour	Minute
Determined or calculated Parameters				
t_G	Generator set running time	Monthly	Hour	Minute
E_S	Battery charge level – Energy in Battery		Hour	Minute
E_{REN}	Energy from REN sources	Daily	Hour	Minute
E_{wtg}	Energy from wind turbine(s)		Hour	Minute
E_A	Energy from PV array(s)		Hour	Minute
E_{hydro}	Energy from micro hydro turbine(s)		Hour	Minute
E_{Th}	Theoretical Energy from REN sources	Daily	Hour	Minute
E_G	Energy from generator set	Daily	Hour	Minute
E_U	Energy supplied to loads (dc and/or ac)	Daily	Hour	Minute
	Fossil Fuel Consumption – may be taken from site logs	Monthly	Monthly	Monthly
I_{dc}	dc current measurements	Daily	Hour	Minute
I_G	Generator set current	Daily	Hour	Minute
I_U	Current at the utility input	Daily	Hour	Minute

III.4 Data Collection

The topic of data collection is beyond the scope of this document but is critically important to insure accurate and valid data collection. As has been previously stated, proper applied measurement techniques are an art that must be learned. It is one thing to specify the proper signals or phenomena to investigate, it is quite another to design the measurement system, install the sensors, write the code for the data logger, calibrate (and regularly re-calibrate!) the complete system and produce reliable and valid information.

III.5 Minimum Data Requirements

The Minimum data requirements for the Benchmarking project basically pertain to measurements covering system operation and generally fall in line with the second level data acquisition specified previously, system performance monitoring. Since the benchmarking project is mostly interested in the operation of field power systems, it is assumed that the most widely available system information is being recorded at one (1) hour intervals and that this will be the most widely available. If data with a higher collection rate (smaller storage interval) is available, this should be used to ensure better system analysis. Hour data is the basis of most simulation models and is the interval of most generally available resource data. Data submitted should meet the additional requirements outlined in the following pages of this general specification.

For the purposes of the Benchmarking project, the use of data from test sites or lab based hybrid power systems is acceptable given adherence to the following two conditions.

I) Renewable energy comes from actual equipment and is not simulated

II) Load provided by the power system must, to the satisfaction of the specific organization submitting the data, reflect actual user operation in a stand alone application. For example, a computer controlled load bank with variable load settings based on data taken from a rural community would be acceptable while the switching of bulk resistive loading based on a simple time clock would not.

Calculated measurements of current or load, based on the summation of all other similar parameters at a specific node or point are considered accurate and valid if deemed so by the specific organization submitting the data. For example, if the currents from the devices connected to the dc bus of a power system are measured except for one, the last one can be determined by summing all of the other currents connected to the dc bus.

Adherence to the minimum data requirements will be to the satisfaction of the specific research organization submitting the data. Although all parties understand the benefit of using calibrated equipment that can be traced back to specific calibration standards, it is understood that tracing the calibrations back for many sites may be impossible. If data is certified by the submitting organization to meet the specification set out in this guideline, all other organizations will in principle accept the quality of the submitted data.

At least three months continuous measurement are necessary if these three months can be considered typical for an entire year. If there is a strong seasonal variation, data from a whole year should be available to ensure correct classification. If data over several years is available from a specific location, the data should be broken into several one year periods to allow for ease in processing. Each year of data does not need to follow the calendar year to be useful.

III.5.1 Specific parameters that will be required

Since the Benchmarking project is not interested in determining the efficiency of any charge controls attached to a specific piece of equipment, all current measurements should be taken on the bus side of any charge controllers or voltage regulators. The only exception to this rule is in measuring the battery bank current in ac coupled systems where the energy into and out of the battery bank should be measured both on the grid and battery side of any power conversion equipment. For all other purposes where the efficiency of a particular component is important, measuring on both input and output will be necessary.

III.5.1.1 Required measurements

Site and system information: Geographic location and system information including:

System identification
System climatic region (general): costal, inland planes, mountains
System altitude
Latitude of system
Nominal power
Monitoring period
Total hour of monitoring
Battery type
Battery rated capacity
Number of cell per battery
Number of cell per battery module/block
Protection of storage unit against ambient temperature (if any)

This information is also included in the Standard Evaluation Report - General Information and Climatic data.

Time stamp: Julian day in decimal format, year

dc Bus Voltage; V_{dc}: If a dc bus is found in the system.

Battery bank voltage; V_{S_c}: if different than the voltage of the dc or ac bus.

Current from each renewable energy device; $I_{REN,}$ or I_{wtg}, I_{PV}, I_{hydro}, and I_G if a fuel based generator is being used.

Current into/out of the battery; I_S: In the case of ac coupled systems, current should be measured on the battery side of any power converter or charge controller.
In addition the following values should be available. However, data are useful even without the following two measurements. In all cases, details of the averaging process are required to understand the data for DC currents (see A2).
Current into the battery; I_{TS}: This value should be summed separately based on data sample. In the case of ac coupled systems, current should be measured on the battery side of any power converter or charge controller.

Current out of the battery; I_{FS}: This value should be summed seperatly based on data sample. In the case of ac coupled systems, voltage should be measured on the battery side of any power converter or charge controller.

Current into/out of the inverter: I_{Inv}

Energy into or out of the battery, either recorder or calculated; E_S:In the case of ac coupled systems, battery energy must be measured with a conventional power transducer on the ac side of the dedicated power converter. In the case of dc measurements, current and voltage are used for this calculation. In both cases energy to and from the battery should be summed in addition to the average.

Battery state of charge, S_{SOC}, either recorder or calculated.

Operational status of the backup generator; t_G: Can be determined from monitoring the generator voltage.

Power to the load, both ac and dc: E_U In the case of ac systems, it is preferred that either Power Factor, total power (VA) or reactive power (VAR) should be measured in addition to real power (Watt). dc power is calculated from current and voltage measurements.

III.5.1.2 Resources and climatic data as applicable:

Since this specification is mainly interested in the current into and out of the battery bank, resource data is not required for submission.

For evaluating similar classes of use for other types of components, the following data should be measured.

Wind velocity at turbine height: V_{Wind} (m/s)

Solar irradiance incident on the PV panel: G_I (W/m^2)

Volumetric flow rate of water in stream: V_{flow} (m^3/s).

III.5.1.3 Preferred measurements:

Battery temperature: T_S (C)

Wind direction: V_{dir}

Ambient temperature: T_{Am} (C)

Site description which may include a list of obstructions to either wind or solar and any other relavent information.

III.5.2 Quality of the data to be considered:

Data must have a capture rate of at least 90% for the time period of analysis. Any bad or missing data must be filtered and marked by the supplying organisation. Bad or missing data should be marked in the data file with –999 unless the data can be filled in by the supplying agency. All data pre-processing should be completed by the supplying organisation.

III.5.3 Format for the data

The format of the data will be specified by the Fraunhofer Institut Solare Energiesysteme so that it can be fitted into the evaluation software. This specification will be provided later in the specification for the standard evaluation report.

IV. Conclusions

This paper describes a general approach to the monitoring of isolated power systems incorporating resource driven and dispatchable generators, either based on renewable energy or conventional technologies. The methodology allows for the analysis of most power systems topographies and technologies compared to other existing work that focus more specifically on specific system topographies. This work has also described three levels of data acquisition, depending on the desired outcome of the monitoring system.

The document also identifies a minimum standard of data that will be required for analysis of power systems within the framework of the EU Benchmarking project. Through the analysis of power systems using this specification, the benchmarking project team will hopefully be able to develop a classification system that can be used to recommend specific equipment types for power systems installed world wide.

This document should also ease in the comparison of different technology options for power generation in off grid applications as it provides a common base for system measurements.

V Literature

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IEEE P1526/D5 Draft Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems. The Stand-Alone Photovoltaic Systems Working Group of Standards Coordinating Committee 21, Institute of Electrical and Electronic Engineers, Inc., 2002

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ANNEXES

Sheet A1 : dc VOLTAGE PARAMETERS

Information to be provided		Performances to be attained		
Function	**Signal**	**Performance criteria**	**Levels or Value**	**Remarks**
Measurement	V_{dc}, V_{S_c}, V_{REN}, V_{wtg_c}, V_{A_c}, V_{hydro_c}, V_{U_dc}	Measurement range: Accuracy:	Maximum to be adapted to suit the dimensions of the installation. For example: for a 48V supply, the range will be 0 to 65Vdc 1.0 %	Measurement frequency: sufficient to detect a battery voltage variation corresponding to start of polarity inversion of an element of the battery, less than .1 Hz
	Action	**Interval**	**Requirement**	**Remarks**
Processing	To identify the minimum and maximum values	Measurement interval	Maximum and Minimum values for every time step	Only applicable over long averaging intervals
	Values averaged over test period	Measurement interval	Average for every time step	
Storage	Minimum and maximum values	Storage interval	Single Max and min value over storage interval	Only applicable over long averaging intervals
	Values average over test period	Storage interval	Single average value over storage interval	

Sheet A2 : dc CURRENT PARAMETERS

Information to be provided		Performances to be attained		
Function	**Signal**	**Performance criteria**	**Levels or Value**	**Remarks**
Measurement	I_{U_dc}, I_S, I_{S_c}, I_{wtg}, I_{wtg_c}, I_A, I_{A_c}, I_{hydro}, I_{hydro_c}, I_{inv}, I_{REN},	Measurement range: Accuracy:	Based on expected currents in power flow 1.0%	Measurement frequency: Must be able to detect ac current ripple on dc current through use of filtering or sample rate, 20Hz. A measurement can be made every 1 to 0.1 Hz but the measurement should be an average over a short time period to reflect high frequency variations. Measurement on all parameters allows calculation of data if one sensor is damaged
	Action	**Interval**	**Requirement**	**Remarks**
Processing	Identify current flow into and out of inverter and battery	Measurement interval	Sum positive and negative values as applicable or needed	Recording current flow into and out of a device allows calculation of energy flow. Most applicable for system battery.
	Report average values	Measurement interval	Average every time step	
Storage	Identify current flow to battery	Storage interval	Values every storage interval of charging and discharging current separately	
	Report average values	Storage interval	Values every storage interval	

Information on the time basis used must be given when measuring and calculating the average current into and out of the battery. Calculating the average of the current into the battery based only on the time that there was current into the battery provides a clearer picture of the current dynamics than other values. However, the length of time used for averaging must then also be given for each time period. See: A systematic effort to define evaluation and performance parameters and criteria for lead-acid batteris in PV systems; G. Bopp, H. Gabler, D-U. Sauer; Proceedings of the 13th European Photovoltaic Solar Energy Conference, Nice, France, 1995

Sheet A3: ac Supply Parameters

Information to be provided		Performances to be attained		
Function	**Signal**	**Performance criteria**	**Levels or Value**	**Remarks**
Measurement	V_U, V_G, pf_U, f_U	Measuring range Accuracy	As need based on the application 2%	Power factor measurement may be used to calculate other power parameters
	Action	**Interval**	**Requirement**	**Remarks**
Processing	Determination of average energy flow.	Measurement interval	Average over time step	Voltage of the utility and/or generator can be used to record generator and system operating time by summing the amount of time in a specific sample period there is voltage recorded on each device.
Storage	Values over test period	Storage interval	Average over storage interval	

Sheet A4: ac Power measurements

Information to be provided		Performances to be attained		
Function	**Signal**	**Performance criteria**	**Levels or Value**	**Remarks**
Measurement	E_S, E_G, E_{wtg}, E_A, E_{hydro}, E_{U}.,E_{U_reac}	Measurement range Accuracy	As needed for the specific system 2%	In cases where the power factor can not be assumed to be 1, additional parameters such a the total power, reactive poweror power factor must also be measured.
	Action	**Interval**	**Requirement**	**Remarks**
Processing	Identify energy flow into and out of inverter and battery	Measurement interval	Sum positive and negative values as applicable or needed	Recording power flow into and out of a device allows calculation of energy flow. Most applicable for system battery.
	Determination of average power flow.	Measurement interval	Max, Min, Average as applicable every time step	Measuring frequency identical to battery voltage measurement
Storage	Identify energy flow to battery	Storage interval	Values every storage interval of charging and discharging current separately	
	Values over test period	Storage interval	Max, Min, Average as applicable	

Sheet A5: Solar irradiance measurement

Information to be provided			Performances to be attained	
Function	**Signal**	**Performance criteria**	**Levels or Value**	**Remarks**
Measurement	G_I, G	Measurement range Accuracy	As needed based on specific site 5%	Placement should be horizontal to the array and representative of the irradiance conditions of the array. Second measurement should be parallel to array surface
	Action	**Interval**	**Requirement**	**Remarks**
Processing	Assessment of available solar resource over test period	Measurement interval	Average as applicable	
Storage	Values average over test period	Storage interval	Average as applicable	

Sheet A6: Wind resource measurement

Information to be provided			Performances to be attained	
Function	**Signal**	**Performance criteria**	**Levels or Value**	**Remarks**
Measurement	V_{Wind}	Measurement range Accuracy	As needed based on specific site 1 m/s or about 5%	Number and location depends on data required. Multiple measurements are generally preferred and measurements at different heights necessary. Measurement for solar applications should be on top of the array and accurately measure wind over the array surface.
	Action	**Interval**	**Requirement**	**Remarks**
Processing	Assessment of available wind resource over test period	Measurement interval	Max, Min, Average as applicable	
Storage	Values average over test period	Storage interval	Max, Min, Average as applicable	

Sheet A7: TEMPERATURE

Information to be provided		Performances to be attained		
Function	**Signal**	**Performance criteria**	**Levels or Value**	**Remarks**
Measurement	T_s, T_{Am}	Measurement range Accuracy	-30 °C à + 50 °C 0.5 %	Location and method of temperature measurements is important.
	Action	**Interval**	**Requirement**	**Remarks**
Processing	Assessment of temperature over test period	Measurement interval	Max, Min, Average as applicable	Measuring frequency identical to battery voltage measurement
Storage	Values average over test period	Storage interval	Max, Min, Average as applicable	

Sheet A8: Generator set Running Times

Information to be provided		Performances to be attained		
Function	**Signal**	**Performance criteria**	**Levels or Value**	**Remarks**
Parameter	t_G	Accuracy	1 minute	Generally calculated from monitoring generator operation, either through unit output voltage or other logic value. May also be applicable for measuring when system is operating by monitoring system output voltage.
	Action	**Interval**	**Requirement**	**Remarks**
Processing	Sum of unit operation status	Measurement interval	Sum every time step	
Storage	Total over test period	Storage interval	Sum over storage interval	Counter must be reset every storage interval