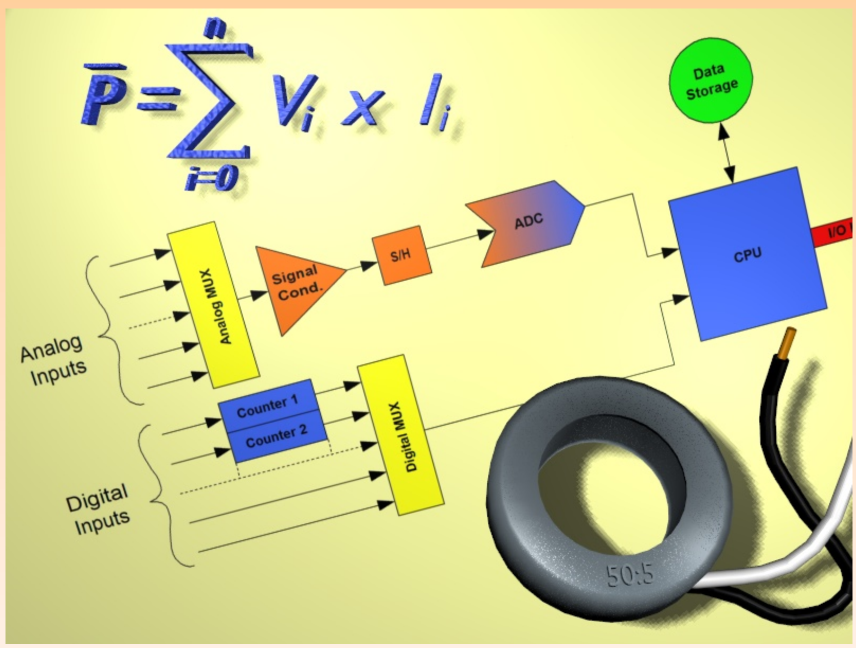
IEA INTERNATIONAL ENERGY AGENCY

Guidelines for Monitoring Stand-Alone Photovoltaic Power Systems

Methodology and Equipment



PVPS

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

IEA PVPS T3-13:2003

IEA PVPS
International Energy Agency
Implementing Agreement on Photovoltaic Power Systems

Task 3
Use of Photovoltaic Power Systems in Stand-Alone and Island Applications

Report IEA PVPS T3-13: 2003

<Guidelines for monitoring stand-alone photovoltaic systems>

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October 2003

Foreword

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organisation for Economic Co-operation and Development (OECD) which carries out a comprehensive program of energy co-operation among its 20 member countries. The European Commission also participates in the work of the Agency.

The IEA Photovoltaic Power Systems (PVPS) Program is one of the collaborative R&D agreements established within the IEA and, since 1993, its Participants have been conducting a variety of joint projects in the applications of photovoltaic conversion of solar energy into electricity.

PVPS is headed by an Executive Committee comprising one representative from each participating country, while the management of individual research projects (Tasks) is the responsibility of Operating Agents. Currently nine tasks have been established. The twenty-one members of the PVPS Program are:

Australia (AUS), Austria (AUT), Canada (CAN), Denmark (DNK), European Commission, Finland (FIN), France (FRA), Germany (DEU), Israel (ISR), Italy (ITA), Japan (JPN), Korea (KOR), Mexico (MEX), Netherlands (NLD), Norway (NOR), Portugal (PRT), Spain (ESP), Sweden (SWE), Switzerland (CHE), United Kingdom (GBR), United States (USA). More details about participating countries can be found on the PVPS program website at: www.iea.pvps.org.

This International Technical Report has been prepared under the supervision of PVPS Task 3 by Dave Turcotte (Canada) and Farah Sheriff (Canada) in co-operation with experts of the following countries: Australia, France, Germany, Japan, Netherlands, Norway, Portugal, Spain, Sweden and Switzerland.

The report expresses, as nearly as possible, a consensus of opinion of the Task 3 experts on the subjects dealt with.

Disclaimer

This document is designed solely as a guideline for monitoring in accordance with the goals fixed by the Task 3 of the International Energy Agency for its work on Photovoltaic Systems for Stand-Alone and Island Applications. It is not intended to be used as a standard and it does not claim to supplement, amend or replace any of the standards referenced hereinafter nor any other existing national or international standard.

Perspective

The *Guidelines for monitoring stand-alone photovoltaic systems : Methodology and Equipment* is one document in a series of related documents prepared by IEA PVPS, Task 3. The other papers are complimentary to this work and any person contemplating investing in a stand alone PV power supply would be well advised to read the other papers in this series. These are all available on the IEA/PVPS web page www.iea.pvps.org.

Report	Code
[1] Guidelines for monitoring stand-alone photovoltaic Systems- Methodology and Equipment	**IEA-PVPS T3-13:2003**
[2] Guidelines for selecting stand-alone photovoltaic systems.	**Under preparation**
[3] Lead-acid battery guide for stand-alone photovoltaic systems	**IEA-PVPS T3-05:1999**
[4] Use of appliances in stand-alone photovoltaic systems: problems and solutions	**IEA-PVPS T3-09: 2002**
[5] Recommended practices for managing the quality of stand-alone photovoltaic systems	**IEA-PVPS T3-15: 2003**
[6] Survey of National and International Quality Assurance Procedures and Standards for Stand Alone PV systems	**IEA-PVPS T3-07:2000**

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1 Introduction

1.1 Objective

The objective of the document *Guidelines for Monitoring Stand Alone Photovoltaic Power Systems – Methodology and Equipment* is to:

- Describe a monitoring procedure that if followed will reassure investors, project managers, performance auditors, equipment manufacturers and servicing firms, that the performance data collected are functionally robust, equitable and representative.

1.2 Background

Investors, project managers, performance auditors, equipment manufacturers and servicing firms frequently require advice about renewable energy technology options and capabilities. More often than not, different system architectures, monitoring procedures and applications, so complicate comparisons between systems that available performance data are rendered next to useless. Adding to the confusion, third parties interested in "sustainable energy" solutions may experience claims and counterclaims about product capabilities and be plied with an assortment of performance data, some derived from the maker's specification, some measured in the field, but nearly all collected on a piecemeal basis without any form of quality management.

In accordance with its current work plan, the IEA PVPS Task 3 needs to be able to analyse the performance of case studies, to determine what comprises a successful, or conversely an unsuccessful, installation. This embodies an assessment process conducive to equitable comparison of different systems at different locations. Having regard to the situation, it was decided to prepare guidelines that establish a functional and consistent approach to performance monitoring for a range of "stand alone" PV system.

Performance assessment involves:

- data collection, which is a straightforward process of measuring parameters;
- evaluation of that data in a manner that provides useful information, which is a complex exercise; and,
- dissemination of useful information to interested parties.

The Guidelines supplement existing documentation dealing with performance monitoring of renewable energy systems and their various components. Task 2 of the IEA PVPS group has prepared a report titled *Operational Performance and Design of Photovoltaic Power Systems and Subsystems*[1]*.* This document has its focus on **Outcomes**, in particular data management and analysis. As such, it complements these Guidelines that have more of a focus on the parameters that need to be monitored.

A set of monitoring **Standards** has been produced by the IEC, titled *Standard for Photovoltaic system performance monitoring*[2]. The focus of the IEC standard is on the electrical performance of PV systems, and it does not address hybrids or prescribe a method for ensuring that performance assessments are equitable. However, units used for the Task 3 Guidelines are consistent with those used for the IEC Standard.

Otherwise, various Standards [6] are being developed around the world for hybrid system design and performance, but none seem to address the issue of the performance comparison of different systems on an equitable basis.

The Guidelines prescribes monitoring requirements that are believed to facilitate the implementation of monitoring and common comparison basis for systems. It is acknowledged that data integrity can best be served by live monitoring and automatic analysis. This is

[1] "Operational Performance and Design of Photovoltaic Power Systems and Subsystems", IEA-PVPS T2-03:2002, Munich, 2001, 64 pages.
[2] "Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis", IEC standard 61724, Geneva, 1998, 37 pages.

technically feasible, and it is recommended as a prime aim of any global data management system established to provide a performance baseline for stand-alone power systems. However, it is also recognised that the capability requires further development to become universally effective, cost effective and convenient under field conditions.

1.3 Need for Guidelines

The Guidelines provide a reference manual in which the information is organised so that a user is able to focus on a specific performance aspect, avoiding irrelevant data collection. The Guidelines starts with a common technical approach but is adapted to the different point of views.

To achieve this, the performance parameters have been organised into customised data sets designed to cover the spectrum of likely monitoring needs. There is a set of general parameters that provide the site information that is universal for all case studies. Thereafter, purpose specific sets include:

- Quality assurance parameters;
- Commercial evaluation parameters;
- Scientific evaluation of system performance;
- Battery performance parameters;
- Appliance performance parameters;
- User-satisfaction and adaptation to technology.

A person proposing to monitor the performance of a system need only peruse the index to identify the set that best suits their purpose, then turn to the relevant section of the Guidelines to view the parameters recommended for measurement.

2 Monitoring Methodology

2.1 Reporting procedure

2.1.1 Content

Monitoring photovoltaic systems can provide useful information about their operation and what should be done to improve performance, but if the data are not reported properly, the effort is wasted. To be helpful, a monitoring report must provide information on the relevant aspects of the operation in terms that are easily understood by a third party.

Appropriate performance parameters need to be selected, and their values consistently updated with each new issue of the report. In some cases it may be beneficial to monitor the performance of individual components in order to refine and improve system performance, or be alerted to loss of performance in time for preventative action. For example, monitoring battery charge/discharge profiles will signal when replacement is due before downtime from system failure is experienced.

2.1.2 Aggregate results

In the typical monitoring situation, output will be sensed every minute, averaged every hour and the result stored. Even with hourly averaging a huge amount of data is generated. To be useful, the raw data must be checked for integrity then summarised.

At the minimum, data needs to be collected for at least twelve months to reflect seasonal variations. Monthly averages are a convenient interval for summarising energy production, consumption and efficiency. When adding or averaging results, always make sure to mention the number of records in the data set. Results must be presented in tabular form (in Appendix of the report) while bar graphs (in the report itself) may be added to give a convenient view of system performance.

Power values can be measured or calculated from V*I values. In AC, the power factor ($\cos(\theta)$ where θ is the angle between the voltage and current) must be considered to obtain the real power. If power is calculated from the voltage and current values on a system that performs averages, the result of the V*I product must be averaged and stored since it cannot be calculated from the averaged voltage and current. In fact, the product of averages is different from the average of products. The following equations demonstrate this limitation for the calculation of average power ($\overline{P}$) using n voltage (V_i) and current (I_i) values.

$$Average\ voltage = \overline{V} = \frac{1}{n}\sum_{i=0}^{n} V_i$$

$$Average\ current = \overline{I} = \frac{1}{n}\sum_{i=0}^{n} I_i$$

$$Power = P_i = V_i \cdot I_i$$

$$Average\ power = \overline{P} = \frac{1}{n}\sum_{i=0}^{n} P_i = \frac{1}{n}\sum_{i=0}^{n} V_i \cdot I_i$$

$$Is\quad \overline{P} \overset{?}{=} \overline{V} \cdot \overline{I}$$

$$\frac{1}{n}\sum_{i=0}^{n} V_i \cdot I_i \overset{?}{=} \frac{1}{n}\sum_{i=0}^{n} V_i \cdot \frac{1}{n}\sum_{i=0}^{n} I_i = \frac{1}{n^2}\sum_{i=0}^{n}\sum_{j=0}^{n} V_i \cdot I_j$$

$$\frac{1}{n}\sum_{i=0}^{n} V_i \cdot I_i \neq \frac{1}{n^2}\sum_{i=0}^{n}\sum_{j=0}^{n} V_i \cdot I_j \quad unless\ either\ V\ or\ I\ is\ constant$$

2.1.3 Format

- Avoid lengthy text with numbers. Use a table format whenever possible.
- If you intent to report on a regular basis on the same system, try to be as consistent as possible on the format of presentation;
- 3-D bar graphs are nice but sometimes difficult to read. Use 3D wisely when reporting results.
- Choose colours and shapes wisely. Remember that a black and white copy of your report will be made at some point.
- Use SI units whenever possible.
- Use the yyyy-mm-dd date format to avoid confusion when exchanging document with people that speak different languages.

2.2 Data Requirements

Equitable assessment of the performance of "Stand Alone Systems" is complicated by system configuration options, application possibilities and cultural variables. The Guidelines recommend individual sets of performance parameters that reflect the use for which the data might be intended. If adhered to, the Guidelines will improve computed data quality, simplify performance analyses and raise the level of confidence in the conclusions inferred from the data, especially for third parties.

In this section, the different measurement points will be explored and classified based on the type of results expected to be achieved through monitoring. Detailed questionnaire templates are available in Appendix A of this document. Questionnaire templates are numbered Q1 to Q8 for easy reference.

Depending on needs and available information, case studies for the IEA database will include General Information as described in section 2.2.1 plus any other data that may be appropriate under the circumstances as detailed in sections 2.2.2 to 2.2.8. However, it is accepted that there may be specific circumstances where the data sets included in the Guidelines need customization.

2.2.1 General Information (Q1)

The General Information data set establishes the where, when, what, why and who aspects of the project. It is included as a minimum standard for any system performance monitoring. In the process it enables the system to be classified in accordance with the Classification System developed by Task 3 as detailed in the IEA publication *Guidelines for Selecting Stand Alone Photovoltaic Power Systems [2].* The Classification System employs a simple key to establish which category of stand alone system the case study best fits, in the process, facilitating equitable performance comparison with other compatible case studies.

2.2.2 System Details (Q2)

To classify the system, detailed information about it must be gathered. The System Details data set touches questions related to the configuration of the system, and the sizing of its key components such as photovoltaics and battery bank.

2.2.3 Quality Assurance Parameters (Q3)

Capital outlaid to purchase a system covers hardware, any associated software and the warranties that underpin the performance claims of the supplier. In some cases it will also cover system installation and provide system support for a specified period.

Unfortunately, many systems are reported as performing below the expectation of the purchaser, earning the technology (and/or manufacturer) a bad name. All to frequently contractual responsibility is unclear and the purchaser is unable to claim the full warranty that was paid for.

This suggests that too little attention is being given to this aspect of the investment. The period of warranty may be inappropriate for a particular application, or the ability to legally enforce it has been negated by an inability to prove where responsibility for a problem lies. Was it the fault of the supplier, the installer or the user?

Questionnaire Q3 covers warranty considerations that should be addressed, both when a system is purchased, and throughout the warranty period. Please consult the accompanying documents for guidelines to improve and maintain quality of systems [5] and information about international quality assurance standards [6].

2.2.4 Commercial Evaluation Parameters (Q4)

Detailed, analytical performance assessment requires costly data acquisition equipment and involves time consuming processing and analysis. While this may be appropriate for pilot or demonstration projects where a considerable research effort can be justified, it is rarely the case once the technology matures commercially.

Project developers using mature technologies are interested to know how the system performs in a commercial sense. Is the system providing the services as planned? What is its availability? Is there a need for maintenance or repair? What is the return on investment? etc. The commercial performance parameters provided in Questionnaire Q4 are intended to answer these questions. By selecting only those parameters of commercial relevance, and conducting local data-reduction (integration, averaging before storage), monitoring costs can be kept low relative to the cost of a comprehensive scientific monitoring exercise.

Questionnaire Q4 provides a suite of parameters that might be monitored for a hybrid system. Simpler systems such as solar home systems will require even less complexity. In a solar home system, one need only measure the input to the charge regulator and the output from the battery to load to gain an appreciation of how the system is performing commercially.

Energy flows can be measured with kWh meters, while outages and demand variations will require a recording instrument such as a data logger.

From the renewable energy sources, only the “useful” energy output will be measured. This may be less than the total energy generation if electricity demand is less than electricity generation while the storage is full. Parasitic losses or energy dissipated in a dump load are also excluded as useful energy.

Power Factor is included as a relevant parameter for commercial evaluation of performance as it will impact on inverter efficiency.

Outages should be logged as soon as noticed. Whenever substantial unexplained differences occur between measurements and expected values, the recording frequency used for the monitoring program should be increased.

Irradiation and wind characteristics are better measured on site. In both cases it is difficult to derive a reliable value using off-site data. Irradiation comprises global, direct and diffuse components. Direct is very difficult to derive from global data, but the need to measure it is limited to instances where solar concentrator systems are to be deployed.

2.2.5 Scientific Evaluation of System Performance (Q5)

The need for technical parameters to develop modelling and analysis tools for stand-alone PV power systems is important because the optimal design of such systems is closely related to how they are operated, and vice versa. The complexity of the modelling will range from a very simple, straightforward exercise in the small scale PV/battery solar home systems case, to a quite involved and complex program in the case of a PV-hybrid (PV/battery/diesel).

Task 3 case studies will, on occasions, involve monitoring of prototype systems where the cost of detailed performance monitoring is justified, and Questionnaire Q5 provides a checklist of the relevant parameters to be monitored in such a case.

2.2.6 Battery Performance Parameters (Q6)

The application of electrochemical storage to photovoltaic power supply systems is less understood, than the more conventional battery applications. The requirement for regular “deep cycling” under all possible climatic conditions seems to bring out discrepancies in the way seemingly identical batteries perform, and this underpins debate about the effectiveness of manufacturers management prescriptions.

Assessing battery performance is a complex exercise. Even quite simple quasi-static battery models used in dynamic simulation programs (e.g. TRNSYS) require the following:

- Current (discharging is negative and charging is positive)
- Voltage (terminal voltage)
- State of charge (SOC, the fraction of remaining capacity divided by total battery capacity on an ampere-hourly basis)
- Nominal battery capacity (Ah)
- Temperature (°C)

In order to determine the battery SOC it is important that the people responsible for operating the systems (or the automatic system), regularly (every 1–2 months) calibrate the total battery capacity. One possible approach is outlined out below:

1) Charge the battery completely.
2) Allow the battery to rest (i.e. no current in or out of the battery) until an equilibrium voltage can be observed (approx. 2–3 hours).
3) Discharge the battery completely.
4) Let the battery rest (i.e. no current in or out of the battery) until an equilibrium voltage can be observed (approx. 4–5 hours)

If the above procedure has been followed, and current (A) and (V) has been monitored, it is possible to calibrate the battery model using the lower and upper equilibrium voltages. An exact battery model is absolutely necessary if an analysis on how to improve the operation of a system with a fixed design is to be performed.

A comprehensive set of battery performance monitoring parameters is shown in Questionnaire Q6.

2.2.7 Appliance Performance Parameters (Q7)

Investment in renewable energy generation capacity is burdened by up-front capital costs, while fossil fuelled plant is characterized by incremental, but high, operational costs. Despite lifetime costs generally favouring renewable energy plant, this situation tends to establish market place bias in favour of fossil fuel plant. To reduce the bias or minimize the need for capital, the renewable energy industry strives to fine tune system load to match system capacity.

A site audit is prerequisite to achieving a functional balance. The audit will include auxiliary equipment such as pumps, compressors, fans and controllers, electrical appliances such as refrigerators, TVs, computers and tools) or lighting demands. Information collected should be in sufficient detail to evaluate efficiency issues as well as obtain a feel for how load may vary over time. The audit will also collect characteristic data (e.g. start-up and shut-off characteristics) for key electrical components. Consequently, it will be possible to recommend best practice for various pieces of electrical equipment.

Alternatively, if no information about the total or fractional electrical loads is available, one could try to estimate these using some key pieces of information such as:

- Number of electrical components from each category (auxiliary, appliances, and lighting).
- Number of people living/using the building on a daily or weekly basis

Information about the type of thermal demands covered by the system should also be collected. This may be cooling (e.g. shading devices, fans, or air-conditioning equipment), space heating (e.g. passive solar heating, wood-burning stoves, electrical heaters, or heat pumps), hot water heating (e.g. gas, electrical, wood, or solar collectors), or high temperature loads (e.g. electrical, gas-burning, or wood-burning ovens). The total thermal demand (kWh) should always be available, along with the sampling time (day, week, month, year).

Alternatively, if no information about the total or fractional thermal loads is available, one should try to estimate these using some key pieces of information such as:

- Building materials used (to estimate an overall heat loss coefficient)
- Number of people living/using the building on a daily or weekly basis.
- Average monthly ambient temperature and humidity (if available).

By following the procedure outlined above, one will be able to determine what fraction of electricity used in the system serves non-high-grade (high entropy) energy purposes (e.g. heating and cooling). Note that using PV-generated electricity strictly for high-grade energy purposes is the first important step towards more optimally designed PV-systems.

A comprehensive set of appliance performance monitoring parameters is described in Questionnaire Q7.

2.2.8 User satisfaction and adaptation to technology (Q8)

There is a range of allied factors that promote the concept of renewable energy programs as distinct from a project. The consequence for any monitoring exercise is that the performance indicators that would normally be associated with a project directed at installing and commissioning a system are no longer adequate. Program assessment requires a new set of performance indicators that measure user adaptation to the introduced technologies. Questionnaire Q8 provides a list of questions dedicated to monitor the extent of satisfaction and adaptation of the user to the system.

3 Monitoring Equipment

The choice of data acquisition hardware is not easy. It is modulated by numerous factors. The purpose of this document is to give some tips and tricks to build precise and reliable systems while avoiding the frustration of falling in typical pitfalls of data acquisition.

3.1 Level of autonomy

Level of autonomy in this case implies three things:

1) Power supply;
2) Number of data points that can be stored; and,
3) Reliability.

The accessibility of the site where the data acquisition (DAQ) system is to be installed, whether it is just next door or on a mountaintop you can only access once a year, will dictate the level of autonomy you require. This is modulated by the fact that people can be located near the site, but it is also greatly affected by their competency and level of interest in picking up data once in a while. This section will describe how to deal with these three elements of autonomy.

3.1.1 Power supply

For stand-alone systems, there are three solutions. For short term monitoring with few readings and without external signal conditioners, a primary battery can be used to power the unit for the time of monitoring. Otherwise, power must be produced on site. The best situation is if you can have your own power supply for the monitoring system but it implies some cost. However, with advance monitoring technology today, it is possible to have units that draw very little power and thus won't affect the system in a significant manner. But, if the system can't suffer any power draw or if the logging function is too power consuming with respect to the site supply, a separate power source must be designed for the DAQ system.

3.1.2 Number of data points

The number of data points grows surprisingly fast. Also, on many systems the date and time are also datapoints. There are four ways to deal with the volume of data:

1) Print them;
2) Store them on a data card that you can collect once in a while;
3) Store them in the DAQ system and get them with a laptop once in a while; or,
4) Use a dial-up connection.

The first three imply that you have to go get the data on site. For short term monitoring, this is fine but for long term, it must be integrated to the scheduled maintenance of the system, otherwise it becomes prohibitively expensive to make a special trip to the site to get the data. Whenever possible, a dial-up connection is preferred, but accessibility and cost of phone line may render this impractical. Cell-phones may also be used for dial-up in areas where the cell phone coverage is adequate.

3.1.3 Reliability

Reliability depends on:

1) How you choose your equipment; and,
2) How you use it.

One important rule: "One must not expect a piece of equipment to do what it's not meant for." This seems straightforward but this rule is often breached. Look at the specifications, temperature, voltage, common mode range (which is often overlooked), etc., and choose wisely. Also, try not to be too impressed by bells and whistles. While some features can be very useful for a specific application, other features may draw power that you can ill afford. Trust systems that have been out there for a while. You don't want anything to go wrong, but if it does, you want a quick answer.

The second point is what you do with the equipment. Here is a little list of tips that are often overlooked and that cause the death of many systems.

Mechanical/environmental considerations

- Put your DAQ system in an enclosure to avoid dust build-up;
- Ensure sufficient cooling;
- Use silica gel whenever possible to avoid moisture build-up in your DAQ system;
- In dry regions (poles or deserts), sometimes you have to shunt your high impedance inputs a bit to the ground (with a 10 kΩ - 100 kΩ resistor) to avoid accumulation of static electricity;

Measurement techniques considerations

- Use a shunt whenever possible to measure DC current;
- For AC current, choose current transformer with low hysteresis;
- Make sure that your measurement technique does not significantly affect the value you are trying to measure;
- Use differential inputs whenever possible;

Electrical considerations

- Keep wires short;
- If you need isolation when measuring DC current, closed-loop hall effect sensors are a good alternative;
- Watch for current loops,
    - Use single point-earthed shielding,
    - Do not share the same wires to carry power and transmit analog signal,
    - Avoid multiple ground connections;
- Use the least vulnerable form of signal transmission available,
    - Convert to digital as soon as possible,
    - Use current transmission whenever possible since series transmission is less vulnerable to noise,
    - Boost low voltage signals close to the source if you have to transmit it on a long distance;

Data quality considerations

- Never have less than two weeks of slack with your data collection agenda. It is not always possible to collect data on the exact date. Think about holidays, summer vacations, sick days, travel etc.; if you want to download data every month, have at least 45 days of storage;
- Find precisely the location of the site (longitude, latitude, altitude) to be able to compare your measurements with statistical values;
- Prepare and follow a calibration schedule;
- Keep a logbook of the monitoring system that includes maintenance, failures, manual interventions and changes of configuration or components.

Troubleshooting considerations

- Choose every component on quality not cost (even a tiny resistor). In a remote location, the real cost of replacing a failed component may only become evident when it fails;
- Keep an up-to-date copy of the plans and layouts;
- Take pictures of the system so you may help somebody repair it if something fails;
- If you have sufficient resources, keep a spare of each of your sensors so you can undertake quick repairs and avoid downtime while performing calibrations.
- Have a comprehensive documentation of your DAQ system.

3.2 Choosing the logger

One may think that when he knows what he has to measure, the choice of a logger becomes straightforward… Wrong! That is just the beginning of the compromising phase. The figure below shows the block diagram of a typical data logger system.

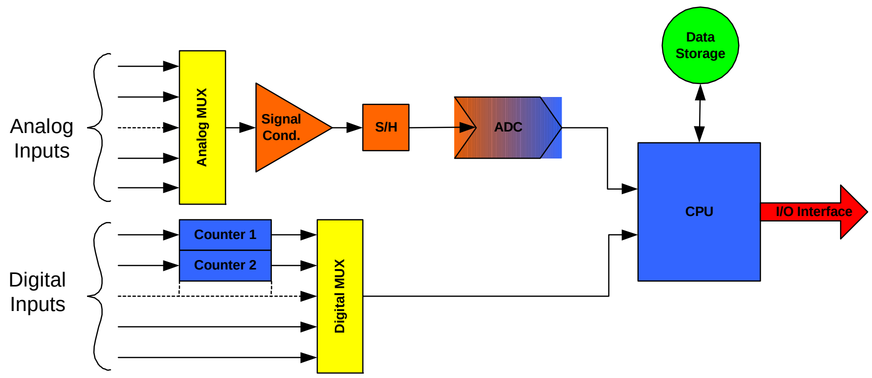


Figure 1. Block diagram of a typical data logger

The structure may change quite a lot depending on the features of the logger but the main blocks will remain:

ADC (Analog to digital converter)

The ADC is the core of the logger unit. The ADC is the circuit that converts an analog voltage signal to a digital value of n bits.

CPU (Central Processing Unit)

The CPU is the brain of the logger. The functions performed by the CPU may range for a simple interface with the ADC for computer driven loggers to a full-featured programmable unit for autonomous loggers.

Data storage

Again, the distinction between computer driven units and autonomous units is very important. Computer driven units will usually have a buffer of only a few samples because it is assume data will be stored on the hard drive of the attached computer providing virtually infinite capacity. Autonomous units on the other hand store the data on board or on memory cards where millions of samples storage capacity can be achieved.

MUX (Multiplexer)

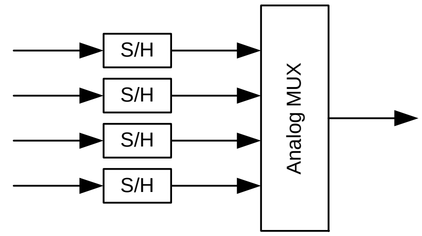
Since loggers usually have only one ADC a multiplexer is used to select the desired input source. Multiplexers are also used in controller units to activate outputs.

S/H (Sample and hold)

While the signal at the input of the data logger may vary with time, the conversion from analog to digital is never instantaneous. Consequently, the reading may be affected by this variation. To avoid this, a sample and hold circuit is used to maintain the signal constant during the conversion.

Some sophisticated units dedicated to perform simultaneous readings of multiple channels will have

S/H chips on each channel to ensure that all channels are sampled at the same time.



Signal Conditioner

The real-life signal can be anything (voltages, currents, resistance, temperature, etc) while the ADC circuit only accepts a fixed range voltage signal. The role of the signal conditioner is to convert the real life signal to the appropriate voltage range for the ADC.

When selecting a data logger unit, the exact internal behaviour is not important but one still need to know what happens to his or her data in order to do a judicious choice. To do so, a certain number of parameters are provided by the manufacturer to help the user makes a choice. The following list gives an overview of these features/characteristics and what must be looked at when choosing the logger:

<u>Specifications pertaining to analog signals</u>

Wiring method

Voltage reading analog channels can be either specified as single-ended or differential. The single-ended wiring method assumes that all sensors can share a common connection point for one of their signal transmission wires. In many cases, this point will be the ground of the DAQ system. In differential, the DAQ system measures the difference between the two wires, allowing both wires to be at any voltage within the common mode range of the unit. A more detailed description is provided in section 3.5.2. Other sensors such as RTD and strain gauge will require different wiring methods that should be investigated prior making a choice.

Number of Channels

The number of channels is unit specific. Loggers often allow converting differential channels into 2 or even 3 single-ended channels hence doubling or tripling the channels available.

Channel Expansion

Allows the use of other modules to increase channel capacity.

Common Mode Range

This is the maximum voltage any single input can take without impairing the operation of the unit. A high common mode range can be useful if a shunt has to be placed on a live wire or if a DC voltage has to be measured on a point of high voltage.

Common Mode Rejection Ratio

Often written as CMRR. This is the ability of the logger to ignore the common mode voltage. This value is expressed in dB. The error (V_{error}) cause by the common mode voltage (V_{cm}) can be calculated as follow:

$$V_{error} = V_{cm} \cdot 10^{-\left(\frac{CMRR}{20}\right)}$$

e.g.: for a data logger having a CMRR of 90dB, measuring a shunt (50 mV) at a voltage of 5 V above ground will introduce an error of 0.158 mV on the reading or 0.3% This may seems low but at 5% load (2.5 mV), this shunt reading will be off by 6%. This shows well that for small signals, it is important to have a high CMRR and to keep the common mode voltage low.

Type of input

Many types of inputs can be available: voltage, current, resistance, thermocouple, strain gauge, etc. Depending on the logger, different types will be available and configurable via software or dipswitches. Not all logger inputs are bipolar so care must be exercised when connecting the sensors.

Resolution

It is an important feature for the accuracy of data collected. It usually ranges from 8 to 15 bit. If all bits are significant, the resolution, in measured unit, can be estimated by full-scale value/2^{n_bits}. For example, a 5 V channel on a 10-bit logger will have a resolution of $5/2^{10}$ i.e. 4.9 mV.

Sample rate

The sample rate is expression in number of conversion per second. This is the speed at which the data is collected.

ADC method

The analog to digital conversion method can be is closely tied to the sample rate and resolutions. The table below summarize the characteristics of the different ADC types:

Table 1. Comparison of different analog to digital conversion methods

Type	Typica Sampling Rate	Typical Resolution	Noise Rejection
Successive Approximation	50kHz - 1MHz	8-16 bits	Low
Integrating	below 30Hz	12-24 bits	Very Good
Flash	above 1 MHz	4-8 bits	None
Delta-Sigma	Wide range 50Hz - 250kHz	8-20 bits	Good

Where speed is not an issue, a Delta-Sigma or Integrating ADC will be excellent. The advantage of integrating ADC is that it allows to adjust the integrating period to a value equal to the power line period (20ms for 50Hz or 16.7ms for 60Hz) thus improving the rejection of this major source of noise.

Specifications pertaining to digital signals

Digital Channels – Input/Output

Useful to generate digital transition events to trigger data acquisition or to control relays. Those channels are often configurable in input or output mode. Otherwise, they are presetted as input or output.

Counter Channels – Fast/Slow

Speed and range of the counter are configurable. The logger counts even when logger is in stand-by mode reducing power consumption.

Other specifications

External sensor power-up

Some loggers provide an output to power external sensors. This is usually linked to the stand-by mode feature of the logger. This feature allows to power signal conditioners and sensor only when a measurement is about to be taken. This is particularly useful for low power systems. Special care must be taken to choose sensors that can be used intermittently with a short start-up time. If the power drawn by the sensors is higher than the allowed power from the logger or if the voltage level is inadequate, a relay can be used.

Communication interface

A lot of interfaces exist today: Serial (RS-232, RS-485, USB) Parallel (SPP, EPP, ECP), GPIB (IEEE 488), Ethernet, etc. For autonomous loggers, the RS-232 is still a convenient interface. It is found on most computers and it allows direct cable connection or dial-up connection (with a standard modem) to download data.

In all cases, interfaces should always be isolated in some sort otherwise, if there is a failure of the DAQ system, the attached computer or other device may be damaged.

Removable Data Card

Allows data storage on a card that can be replaced. This is very useful to transfer data from a local without communication means other than somebody that pass by once in a while.

Internal Battery

Allows the logger to continue acquisition when external power supply is not available. Coupled with the power requirements, this will define the autonomy of logger when operating in stand-alone mode.

Power Requirements

When power is not available from utility, the logger needs to have very low power consumption. Usually, power consumption will vary with respect to the number and rate of channels acquired.

Stand-by mode

The logger can have a built-in “sleep mode” that allows it to limit the energy consumption of the system.

Temperature Range

Some loggers can support ambient temperature variation from –55°C to 70°C.

Different kinds of loggers are available in the market. You can find full-blown models with multiple features for specialized application or models with fewer features but that offer a low cost alternative. Whatever your needs are, chances are you will find a data acquisition system that can fulfil them. However, whatever logger is chosen, it will always be a compromise between cost, features and ease of use, so cost must not always be the decisive factor. It is also advisable to choose with future needs in mind. Learning all the nuts and bolts of a new logger model is time consuming, so sticking to a logger type/model will often save time and avoid surprises such as no data for six months due to a missing configuration parameter.

3.3 Choosing the sensors

Choosing the right sensor is important because that is where your first measurement error gets in the loop and no matter how precise the data logger is, once in, the error will stay. Sensors have to be chosen alongside with the data logger. There are various ways to measure a single value, but the choice made will affect the logger requirements and the method of measurement may require adjustment to fit within the cost and power limits established.

Before looking at measurement techniques, here are the basic rules of data acquisition.

- Limit impact on the system operation;
- Avoid intermediates;
- The simpler the better;
- Add some redundancy;
- Match sensor and system ranges.

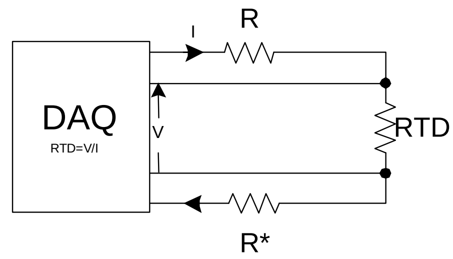
3.3.1 Temperature

Common sensors to measure temperature are thermistors, thermocouples and RTDs (Resistor Temperature Devices). The following table describes the different sensors and their pros and cons.

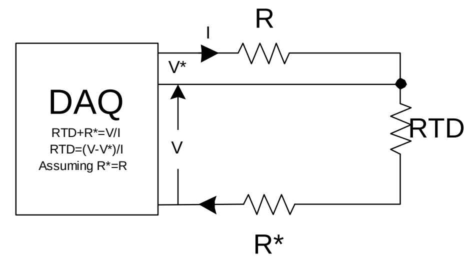
Table 2. Temperature Sensing Elements Comparison

Sensor	**Thermocouple**	**Thermistor**	**RTD**
Active element	Two different metals coupled together	A semiconductor plate	A platinum wire
Output	A small voltage proportional to the temperature	Resistance vary with temperature	Resistance vary with temperature
Linearity	Good	Bad	Excellent
Approximate Cost **(probe unit)**	Low (US$8)	Medium (US$45)	High (US$85)
Sensitivity	Low	High	Low
Precision	Medium (0.5-1°C)	Medium (>0.5-1°C) with a good equation	High (≈ 0.1°C)
Distance	100 m	> 300 m (4 wire conf.)	>300 m (4 wire conf.)
Application	Excellent for general temperature measurement for a limited range of temperature (ΔT<60°C).	Excellent on a very small range of temperature (to trigger an alarm for example) but bad for DAQ on a wide range.	Excellent for high precision measurement on a wide range of temperature (ΔT >100°C).

Most of the time, thermistors are not appropriate for DAQ applications due to their lack of linearity. They often need a special signal conditioner, which is cumbersome in DAQ applications. RTD on the other hand are very precise, but their high cost often deters users. Moreover, they will require a DAQ unit that supports RTD, which is not as common as for thermocouples. To conclude with RTDs, let's say that the sensitivity is very low so to measure the resistance accurately, a 4-wires measurement is preferred. 3-wires can be used but be warned that not all manufacturers fully support the 3-wire compensation. The following figures show the configuration and compensation for 4 and 3-wire RTD measurements.



4-wires



3-wires

Figure 2. RTD Connection Arrangements

Usually, a thermocouple is sufficient to provide a good resolution. For PV monitoring applications, a T-type thermocouple is preferred since it has a temperature span going from -270°C to 400°C for thermocouple grade, and -60°C to 100°C for extension grade covering whole spectrum of applications. K-type thermocouples are more commonly found but their precision is lower and the extension grade is not suitable for sub zero temperatures, which may be a problem for cold regions.

One drawback with thermocouples is that they need special extensions and connectors to allow the continuity of the metal used. This is a minor problem because extensions are easy to find and cost less than US$1 a metre for good quality wire.

Temperature sensing elements are also offered in different shapes to accommodate the type of measurements to be taken. For example, to measure the temperature of a PV module, a flat sensor, solidly fastened to the back of the PV module will be preferred. For free air measurement, a radiation shield, a bulb that covers the sensor while allowing the air to pass through freely, should always be used to avoid the effect of rain, wind and direct sun.

3.3.2 DC Voltage

Voltage measurement is probably the easiest measurement of all since all monitoring units have that capability. Most of the time, a simple pair of sensing wires will be sufficient. If the voltage is too high for the input of the data logger, a voltage divider is used. Here are a few rules of thumb about voltage dividers though:

- The impedance of the output resistance of the voltage divider shall be at least 100 times lower that the impedance of the data logger input;
- The power dissipated through the resistance of the voltage divider shall not exceed 10% of their nominal power to limit heating it up;
- Metal film, low temperature drift (<25 ppm/°C) resistors are preferred.

If direct measurement is impossible, modular isolated signal conditioners are available on the market with multiple output types.

3.3.3 DC Current

Measuring DC current can be done either with a shunt or with a hall-effect sensor.

Shunts are simply low value resistors that will output a voltage proportional to the current flowing through them. While shunts will offer the highest precision, they also have two drawbacks. First they offer no isolation, and second they need you to break the current path.

Since they are not isolated, caution must be exercised with the placement of shunts if they are intended to be measured directly by the logger. A common mistake is to place shunts on live wires leading to a high common mode voltage (Vcm). If direct measurement of shunts is intended, all shunts should be placed as close to the neutral as possible to avoid errors (see common mode rejection ratio) and potential damage to the unit. The following figure illustrate the issue with the common mode voltage and the placement of shunts. If the system is floating, in the sense that there is no neutral point, signal conditioners shall be used to transmit the voltage to the logger.

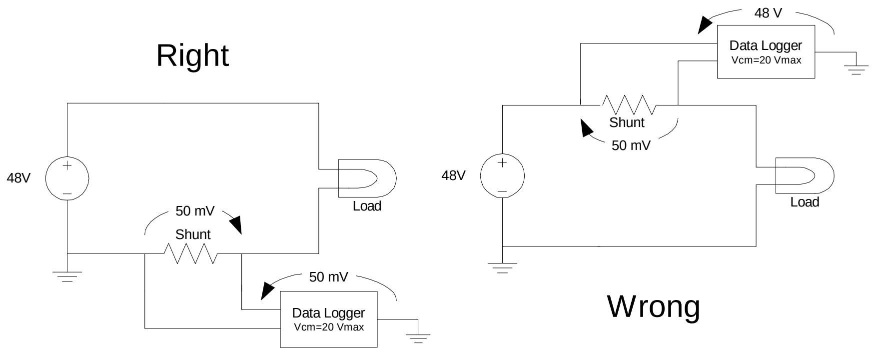


Figure 3. Common mode voltage issue with shunts

Hall effect sensors, though often less precise than shunts, offer multiples advantages. Two main categories of hall-effect sensors are marketed, open-loop and closed-loop sensors. The difference between these two resides in the way the hall-effect element is used. With open-loop sensors, the hall-effect element is used to give a linear reading of the magnetic field, which is then converted into current. In closed-loop sensors, a counter-current is used to nullify the magnetic field and the hall-effect element is then used to determine if magnetic field is present at all, thus leaving out any non-linearity the element may have. Generally, closed-loop sensors are more precise, but they also are more expensive. The main drawback of this type of sensors is that they need external power. Hall-Effect sensors are relatively easy to find. Split-core sensors on the other hand may cause more trouble

Table 3. DC Current Sensors Comparison

	Shunt	**Hall Effect Sensor**
Need external power	N	Y
Isolated	N	Y
Error	<1%	1-5%
Temperature effect	low	Medium
Break current path	Y	N
Exist as clamp on devices	N	Y

3.3.4 AC Measurements

Most of the time, AC measurements will be used to get the power or energy output of the system. Consequently, there is little interest in the voltage and current values themselves. If voltage and current values are required, individual signal conditioners can be used to convert the values into acceptable inputs for the logger. Current will most of the time be picked-up by current transformers. Shunts can also be used but they do not provide isolation.

Moreover, energy meters can be useful to control the consumption for village power for example.

WARNING: *The output of current transformers must be loaded at all time during operation, otherwise dangerously high voltage may arise. Never place quick disconnects or* *attachment plugs between a current transformer and its load.*

Wattmeters will take a current input, directly or from a current transformer, and a voltage input. Depending on models, wattmeters will provide one or more of the following:

- Real power (W)
- Apparent power (VA)
- Reactive power (VAR)
- Power factor
- Energy count (Wh per ticks)

Here are a few tips to choose watt transducers:

- Range of wattmeters is usually given in VA, so the power factor of the equipment must be taken into account when choosing the transducer;
- All wattmeters do not have the same frequency response. True RMS wattmeters must be used at the output of a modified square inverter or other noisy equipment (including loads).

3.3.5 Solar Radiation Measurement

The choice of a sensor for PV radiation measurement will depend on the investment one is ready to make for such a measurement. The following table gives of overview of the different technologies available.

Table 4. Solar Radiation Sensors Comparison

	Thermopile Pyranometer	**Photodiode Pyranometer**	**Reference cell**
Principle of operation	Two thermopile, one exposed to sunlight and the other one hidden to measure ambient temperature. The voltage difference between the two is proportional to the solar radiation.	A semiconductor device that will generate a current proportional to solar radiation.	A shorted solar cell is used. The current generated is proportional to solar radiation.
Error due to temperature	< 0.2%/°C	< 0.5%/°C	< 0.5%/°C
Acceptance angle	High	Moderate	Low
Error due to spectral shift	Low	High	High
Stability over time	High	Moderate	High
Typical error	< 1%	< 5%	< 5%
Cost (approximate)	US$1800	US$300	US$100-2000

Precise solar radiation measurement is generally required only for research purpose in which case, a thermopile pyranometer will be the tool of choice. Otherwise a simple photodiode pyranometer or a reference cell can do the job. If reference cells are used, caution should be taken to match the technology of the reference cell with the technology of the photovoltaics used.

Average solar radiation falling on a place can be estimated mathematically if you have the latitude, longitude and tilt of that plane. The equations are very well explained in Duffie and

Beckman "Solar Engineering of Thermal Processes" published at John Wiley and Sons[3]. However, some factors as ground albedo or cloud cover are often difficult to estimate. Measured averaged ground radiation data can be obtained from weather services of the different countries. However, many locations of the globe do not have ground weather stations, in which case, satellite data can be used. The NASA Langley Research Center now offers to the wide public the results of their worldwide satellite measurements through their website at http://eosweb.larc.nasa.gov/sse/. This is an excellent resource when ground data are not available.

3.3.6 Wind Speed and Direction

Wind speed and direction can be an important parameter for thermal analysis of system shelters and photovoltaic array performance. If only wind speed is important, a simple 3-cup anemometer will do the job. These units cost around US$200-US$450. If both wind speed and direction are required, there are four options:

Single propeller on a vane	Economical unit. Precision is however impaired by the fact that the vane and the propeller are disturbing each other. (≈ US$900)
3-cup anemometer and vane	Often the preferred option because wind speed is measured independently of the direction while being at a reasonable price. Moreover, units (anemometer and vane) can be replaced separately. (≈ US$1200)
3-axis propellers	Three propellers in X, Y and Z measure the wind in all directions. This type of equipment is excellent for measurement of turbulence. (≈ US$2000)
Ultrasonic anemometer	This is one of the latest innovations in wind measurement. Having no moving parts, these require little maintenance and calibration. (≈ US$2200)

3.3.7 Other sensors

Other sensors may be useful for scientific study of PV systems. Though humidity has little effect on the equipment itself, it may change the solar spectrum, thus affecting the performance of photovoltaic modules. Solid state humidity sensors are available on the market, usually from companies specialised in meteorological instruments. Always use a radiation shield with humidity sensors. Single probes measuring both temperature and humidity are also available.

The temperature of crystalline silicon PV-array affects the overall performance of the system. Simply measuring the temperature of the array may be sufficient to calculate the actual performance but is not sufficient to predict the behaviour in other insolation, wind and load conditions. The best case is of course if the overall heat loss coefficient (W/m2) and the thermal capacitance (J/K-m2) is readily available, but this is seldom the case. Combined with physical placement (air gaps), ambient conditions (insolation, wind) and load (how much electric power is flowing out), thermal elements such as thin film heat flux sensors can be used to characterize photovoltaic modules thermal parameters.

[3] Duffie, John A. and William A. Beckman. *Solar Engineering of Thermal Processes, Second Edition.* New York, NY: John Wiley & Sons, Inc., 1991, 917p.

3.4 Choosing the Signal Conditioners

Signal conditioners are versatile devices. They allow you to convert signals from one form to another more suitable for data acquisition needs. For example, to get the AC power out of an inverter, the following equation needs to be resolved: $V_{rms} \times I_{rms} \times \cos \phi$. This may seem trivial on a calculator, but loggers don't support cosines and few will be able to measure the RMS (root mean square) value of an AC signal. Most of the time a signal conditioner will be used to do the job.

Another reason to go for a signal conditioner may be simply to amplify or convert the signal into a less vulnerable signal. For example, if a pyranometer having a gain of 10 $\mu V/(W/m^2)$ is located 300 m of the data acquisition system, the signal is likely to pick-up a lot of noise along the line. It becomes desirable to "boost" that signal near the sensor with a 25 mV / 5 V amplifier or convert it into a current loop with a 25 mV / 4-20 mA signal conditioner.

When choosing a signal conditioner, the following information must be considered:

- Level of isolation (to avoid destroying all the system if one component fails);
- Supply voltage (one must remember that a 24 V battery bank can go up to 28 V easily)
- Warm-up time (if used intermittently);
- Temperature of operation;
- Temperature stability;
- Field configurability (stay away from units that need a computer to get configured);
- Polarity (many units are unipolar and will not be appropriate to measure current flow for example).

3.5 Wiring Techniques

Wiring may seem evident but that is not always the case.

3.5.1 Choosing the Correct Wires

Instrumentation wires are available in a multitude of types and brands. Following is a list of features and elements to look at.

Size	Current used for signals is generally low so the size is generally dictated by practical needs and perhaps the current required to power the sensors.
Stranding	This is the number of small strands or threads in each single wire. The more strands you have, the more flexible is the wire. Most of the time, you want to avoid single core wires since they will tend to be less reliable due to their tendency to break.
Material	Copper is the most common type used. Aluminium must only be used with active compression connection. Tinned copper is often preferred since it reduces the corrosion factor.
Type of cable	Apart from standard cables where wires run parallel to each other, there are twisted pair and coaxial cables. Twisted pairs, as its name tells is simply accomplished by twisting each pair of wires. This allows higher noise immunity, especially if shielded. Coaxial cables are built by having a central conductor surrounded by the shield, which is also the second conductor. This gives the highest immunity but is very expensive and often impractical.

Shielding

Shielding can be common for the whole cable or individual for each pair of wires. Individually shielded pairs will avoid cross-talk between pairs.

Isolation level

Expressed in volt, this is the maximum voltage allowed in the cable.

Isolation type

This is the material used for the jacket of the wires and cable. Three factors must be considered: 1) chemical resistance, 2) mechanical resistance and 3) UV stability. Different material will have different resistances to chemical substances. For example, nylon is not good near batteries where sulphuric acid is present. Requirements for mechanical resistance are defined by the exposure of the cable to human interaction and weather. Finally, the UV stability is very important for wires intended to be installed outside. If not chosen properly, isolation will crack and cause short-circuits.

Coding

Wire coding in a cable is done either with colours or with numbers. The choice is to user discretion. Numbers are often difficult to read on wires but for a colour-blind, this is a small price to pay.

Impedance

Wire impedance is expressed in ohms. DC or low frequency AC signals over a short distance are not affected by wire impedance. However, for wires used for communications (Ethernet, RS232, RS485 or analogue) the impedance becomes a key parameter. If the transmitter/receiver does not already have one, a termination resistor must be added to match the impedance.

3.5.2 Wiring the System Together

Wires intended to carry power shall always have overcurrent protection. A fuse or breaker will protect the wire, but also avoid bringing the whole system down if something goes wrong with one sensor. The same rule should be followed with signals with potentially high current, like battery voltage. In this case, protection can also be achieved by placing a resistance in series with the wire. Care must be taken however not to alter the precision of the reading by doing so.

As mentioned earlier, either single-ended or differential input can be used. Figure 4 shows the connection difference for two thermocouples.

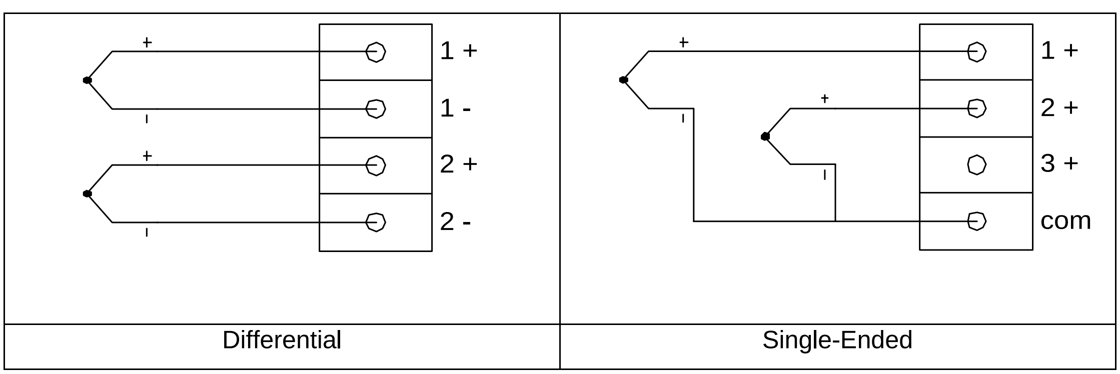


Figure 4. Comparison of differential and single-ended connection mode

Single-ended connections require less wires and simpler acquisition systems. However that is where the advantages stop. They present also a lot of drawbacks such as:

- Higher cross-talk between channels;
- Higher vulnerability to noise;
- Perfect condition to create current loops;
- One wire must be common (grounded); and,
- Decreased reliability since many channels depend on a single wire.

This does not mean that single-ended should not be used, but simply that the designers must be careful in their use. Signals can be grouped under the single-ended method only if:

- The common does not become a supply wire (total or partial);
- All sensors are floating (no reference to the ground) or the common to all sensors can be connected at only one place on the system;
- The supply of the DAQ system, if connected to the DAQ common, has no direct connection with the unit being measured, otherwise current may flow. This may be corrected with isolated DC/DC converters.

Finally, special care must be taken in proper shielding of signal cables. Theoretically, best shielding is achieved by grounding the shield at both end of the cable. Unfortunately, practically, it is rarely the case, since ensuring that both ends are at the same potential is impossible. Consequently, the best practical way of shielding is to ground the shield at the data logger side. Many loggers have a ground screw or lug for this purpose.

The shield may not be used as a current carrying wire since it will inject noise. Also, the ungrounded end of the shield must be isolated to prevent inadvertent contact with the surrounding.

3.6 Tips for successful monitoring

To conclude this document on monitoring equipment and protocols, here are a few rules of thumbs:

- Use a shunt whenever possible to measure DC current;
- If you need isolation when measuring DC current, closed-loop hall effect sensors are a good alternative;
- For AC current, choose current transformer with low hysteresis;
- Make sure that your measurement techniques do not affect significantly the value you are trying to measure;
- Choose low power consumption sensors;
- Watch for current loops;
- Add some redundancy;
- Whenever possible, use the less vulnerable form of signal transmission available;
- Choose every component as you would do for a US$5000 piece (even the tiny resistor), it may be the cost involved to replace it when it fails;
- Keep a logbook of your system;
- Keep an up-to-date copy of the plans and layouts;
- Take pictures of the system so you may help somebody repair it if something fails;
- Find precisely the location of the site (longitude, latitude, altitude) to be able to compare your measurements with statistical values;
- Prepare and follow a calibration schedule;
- If you have sufficient resources, keep a spare of each of your sensors so you can repair quickly and avoid downtime while performing calibrations.

4 Conclusion

The renewable energy industry is emerging from its “backyard” industry identity, to earn a degree of respectability in corporate circles. This “coming out” process is accelerating, as global environmental and social concerns raise moral issues and translate into higher insurance premiums and social discontent.

The involvement of utility scale businesses in the industry is providing pressure for sensible standards and performance guidelines, but the introduction of effective measures is fraught with difficulties. The task requires that the performance of complex system technologies, used in complex applications, be compared on an equitable basis.

As outlined though this document, equitable performance assessment of photovoltaic systems required the combination of four key elements:

- Good knowledge of the system
- Accurate measurement techniques
- Quality procedures
- Reliable data gathering

Methods as presented in this document should allow to gather quality in order to achieve a rigorous assessment of “performance” in all of its spheres, namely: technical, financial, environmental and social acceptance. Nevertheless, these Guidelines are not presented as the final answer to the problem. Persons using the Guidelines will no doubt encounter difficulties with some of the prescriptions contained therein, and may well develop alternative approaches that are more useful in their circumstances. When this happens, it is important that they contribute to the process of refinement by contacting Task 3 with a description of the improvement.

Appendix A

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Questionnaire

Templates

Introduction

This appendix present a set of questionnaire templates to defined the required parameters in order to perform exhaustive analysis of a system with respect to eight different goals namely:

Q1: General information
Q2: System details
Q3: Quality assurance parameters;
Q4: Commercial evaluation parameters;
Q5: Scientific evaluation of system performance;
Q6: Battery performance parameters;
Q7: Appliance performance parameters;
Q8: User-satisfaction and adaptation to technology.

In all cases, a general description will be required to at least what type of system is looked after. The system details will be required whenever some technical details or classification will be required.

Parameters defined in Q3 to Q8 will be used accordingly depending on the questions answers are looked for. Here are a few examples:

1. System suppliers may want to use Q8 to assess user-satisfaction and Q4 to help troubleshoot his systems.
2. Research organisation will most probably refer to Q5 for research purpose and Q6 is heavily involved in battery performance issues.
3. Project funding agencies will want to assess the quality of the installation done by the suppliers and will consider the Q3 subset.
4. The manager of a village power system may want to assess the impact of new appliances on the local grid and could use template Q7 for this purpose.

Q1 General information

Location

Country: ____________________
Region: ____________________
District: ____________________
Site name: ____________________

Contact Person:

Name: ____________________
Company: ____________________
Address: ____________________
Phone: ____________________
Facsimile: ____________________
E-mail: ____________________
Phone: ____________________
Facsimile: ____________________
E-mail: ____________________

System Management:

Owner: ____________________
Installer: ____________________
Operator: ____________________
End user: ____________________
Maintenance: ____________________

Site co-ordinates:

Latitude: ____________________
Longitude: ____________________
Altitude: ____________________

Project type:

Aid: ____________________
Prototype: ____________________
Market demonstration: ____________________
Commercial ____________________

Q2 System Details

System details:

System Classification*: ______________________

Average electricity demand (kWh/d):
(design requirements) ______________________

Array capacity (Wp):
Make: ______________________
Model: ______________________
No of Panels: ______________________

Electrical configuration: (attach schematic): ______________________

Charge controller details: ______________________

Inverter details: ______________________

Commissioning date: ______________________

Array mounting system (short description): ______________________
____
____
____

Battery details:

Manufacturer (name and country): ______________________

Model and reference: ______________________

Rated Capacity:
C10 (Ah): ______________________
C100 (Ah): ______________________

Rated voltage (V): ______________________

Number of cells of monobloc:
In series: ______________________
In parallel: ______________________

No. of days of autonomy ______________________

Resource Data:

Radiation on array plane (W/m^2): ______________________

Ambient temperature (^oC): ______________________

Availability of low ion water: ______________________

* System classification key is outlined in the Guidelines for Selecting Stand Alone PV Power Supply Systems (IEA-PVPS T3-).

Q3 Quality Performance Evaluation

Contractual Information:

List legal contracts: ______________________________

Nominate who is responsible for system: ______________________________

Nominate who is responsible for operation & maintenance: ______________________________

Warranty Details:

System operation warranties: ______________________________

Individual component warranties: ______________________________

Post commissioning system modifications:

Detail changes to generating capacity: ______________________________

Detail changes to civil works: ______________________________

Detail changes to power electronics ______________________________

Detail changes to control system software: ______________________________

Outages:

Type: ______________________________

Duration: ______________________________

Cause, including the service record of the failed equipment: ______________________________

Action taken, with cost born by? ______________________________

Performance assessment:

What parameters are measured? ______________________________

What are the data management provisions? ______________________________

Q4 Commercial System Performance

Average daily load:

Average daily load:
DC (kW) ______________________
AC (kW) ______________________

Energy Flow:

Useful energy from the PV-array (kWh/month): ______________________

Useful energy from each of the other renewqable energy sources (kWh/month): ______________________

Energy from the auxiliary back up system (e.q. a diesel) (kWh/month): ______________________

Energy to the load via the inverter (kWh/month): ______________________

Energy to the battery (kWh/mounth): ______________________

Energy from the battery to the inverter (kWh/month) ______________________

Power Factor: 0 to unity ______________________

Outages of the different system components and loss of load (duration/month) ______________________

DSM provisions: ______________________

Efficiency Measures:

Brefly describe any investment to improve the thermal performance of buildings and appliances: ______________________

Client status (Access to):

Project capital and operational funding mechanisms: ______________________

Technology transfer arrangements: ______________________

Backup from system service technicians: ______________________

Costs:

Number of service users: ______________________

Capital costs: ______________________

Operation & maintenance costs: ______________________

Cost associated with managing the service or program: ______________________

Q5 Technical evaluation

Resource Data:

Global/direct irradiation ((kWh/m^2)/a): ______________________

Wind speed (annual average m/s): ______________________

Other relevant RE resource parameters: ______________________

Load Characteristics:

Daily demand curve dc/ac (power vs.time): ______________________

PV contribution to meeting load (%): ______________________

Capture losses (Wh): ______________________

PV array:

Module average maximum operating temperature (^{o}C): ______________________

Array rated power (W): ______________________

Measured average peak performance (W): ______________________

Array output delivered to inverter (kWh/a): ______________________

Array output delivered to batteries (kWh/a): ______________________

Array outages (h/a). (attach schedule if appropriate): ______________________

Additional Renewable Energy generation (eg wind power):

Energy output of each alternative sources (kWh/a): ______________________

RE output delivered to load (kWh/a): ______________________

RE output delivered to inverter (kWh/a): ______________________

RE output delivered to batteries (kWh/a) ______________________

RE output to dump load (kWh/a) ______________________

Outages (h/a). (attach schedule): ______________________

Auxiliary “backup” system (eg Diesel):

Energy generated by aux (kWh/a): ______________________

Aux battery charging (kWh/a): ______________________

Aux output to load (kWh/a): ______________________

Aux fuel/energy input ______________________

Outages attributable to Aux. System (h/a) (attach schedule) : ______________________

Energy efficiency provisions:

Building design (Briefly describe any investment to improve the thermal performance of buildings). ______________________________

Appliance and tool load & efficiency (Briefly describe results of the energy audit): ______________________________

Q6 Battery performance

Battery:

Manufacturer (name and country): ______________________

Model and reference: ______________________

Rated capacity:

C5 (Ah): ______________________

C10 (Ah): ______________________

C50 (Ah): ______________________

C100 (Ah): ______________________

Performance @ 20^{o}C and 45^{o}C:

Cycle life (cut-off @ 80% rated capacity): ______________________

Self discharge rate (% of C5/5 capacity/month): ______________________

Internal resistance fully charged: ______________________

Predicted shelf life in dry charged state: ______________________

Physical arrangement:

Nominal voltage (volt): ______________________

Cut-off voltage (volt): ______________________

Number of cells of mono-block:

In series: ______________________

In parallel: ______________________

Battery type:

☐ Solar:
☐ Conventional:

General Technology:

☐ Car or SLI
☐ Traction
☐ Stationary
☐ Flooded
☐ Sealed: ☐ AGM or ☐ Gelled

Plate structure

☐ Tubular plate:
☐ Flat plate: ☐< 4mm or ☐ > 4mm

Grid alloy:

☐ Lead-Antimony %: __________
☐ Lead-Calcium %: __________

Rated specific gravity (fully Charged):

Sediment space (distance between bottom of container and the bottom of the plates, expressed as a percentage of plate height): ______________________

Electrolyte reserve (the distance between the top of the container and the maximum ______________________

electrolyte level, expressed as a percentage of plate height): ____________________
`

Climatic conditions:

Temperature range:
Lowest temperature (^{o}C): ____________________
Highest temperature (^{o}C): ____________________

Other specific conditions: ____________________

Supply conditions:

Ready to use (electrolyte filled): ☐ Yes ☐ No

Dried-charged: ☐ Yes ☐ No

Conditions of installation:

Initial charge recommended: ☐ Yes ☐ No

Initial charge performed: ☐ Yes ☐ No

Conditions of maintenance:

Performed by the end-user: ☐ Yes ☐ No

Performed by technicians: ☐ Yes ☐ No

If yes, frequency? (Months) ____________________

Lifetime:

Date of installation: ____________________

Expected lifetime, if new or still in operation (years of cycles): ____________________

Actual lifetime, in case of replacement (years): ____________________

Reasons for having selected this type of battery:

Price: ____________________

Warranty period: ____________________

Expected lifetime: ____________________

Cycling performance: ____________________

Price / performance ratio: ____________________

Maintenance free: ____________________

Easy transportation: ____________________

Easy installation (no ____________________ electrolyte manipulation): ______

Local distributor: ______

Locally manufactured: ______

Other criteria(s): ______

Cost information:

Other observations and additional information (if necessary):

Protection against active material shedding and plate shorting: ______

Steps taken to minimise electrolyte stratification: ______

Electrolyte level indication: ______

Specific gravity indicator: ______

Automatic electrolyte recharge: ______

Catalytic converters: ______

Battery management system:

If a dedicated device is used, type of regulator of charge controller: ______

Manufacturer (name and country): ______

Reference: ______

If no dedicated device, type of inverter or power control unit: ______

Manufacturer: ______

Reference: ______

Battery management strategy:

Voltage control: ☐ Yes ☐ No

Overcharge protection: ☐ Yes ☐ No

High voltage disconnect (V): ______

High voltage floating current (A): ______

Deep discharge protection: ☐ Yes ☐ No

If yes, setpoint (V): ______

Periodic boost charge function:	☐ Yes	☐ No
Temperature compensation:	☐ Yes	☐ No
Current compensation:	☐ Yes	☐ No
State of charge of Ah control:	☐ Yes	☐ No

If details are known, please fill in details of the algorithm:

Which monitoring data are available?:

Complete battery voltage profile:	☐ Yes	☐ No
Hourly voltage data:	☐ Yes	☐ No
Daily minimum and maximum voltages:	☐ Yes	☐ No
Input to batteries (Ah or Wh):	☐ Yes	☐ No
Battery output (Ah or Wh):	☐ Yes	☐ No

Other data (please specify):

Q7 Appliance performance

Lamps:

Manufacturer (name and country): ______________________

Model and reference: ______________________

Alternative Current? ☐ Yes ☐ No

Number: ______________________

Nominal voltage (V): ______________________

Power (W): ______________________

Mean daily use (hour/lamp) ______________________

Television:

Manufacturer (name and country): ______________________

Model and reference: ______________________

Size (cm diagonal) ______________________

Nominal voltage (V): ______________________

Alternating Current? ☐ Yes ☐ No

Power (W): ______________________

Standby power (W): ______________________

Mean daily use (h): ______________________

Refrigerator:

Manufacturer (name and country): ______________________

Model and reference: ______________________

Size (dm^3) ______________________

Nominal voltage (V): ______________________

Alternating Current? ☐ Yes ☐ No

Power (W): ______________________

Yearly consumption @ 25^{o}C (kWh): ______________________

Daily consumption @ 25^{o}C (kWh): ______________________

Freezer:

Manufacturer (name and country): ______________________

Model and reference: ______________________

Size (dm^3) ______________________

Nominal voltage (V): ______________________

Alternating Current? ☐ Yes ☐ No

Power (W): ______________________

Yearly consumption @ 25^{o}C (kWh): ______________________

Daily consumption @ 25^{o}C (kWh): ______________________

Video:

Manufacturer (name and country): ______________________

Model and reference: ______________________

Nominal voltage (V): ______________________

Alternating Current? ☐ Yes ☐ No

Power (W): ______________________

Standby power (W): ______________________

Mead daily use (h) ______________________

Radio:

Manufacturer (name and country): ______________________

Model and reference: ______________________

Nominal voltage (V): ______________________

Alternating Current? ☐ Yes ☐ No

Power (W): ______________________

Standby power (W): ______________________

Mean daily use (h): ______________________

Washing machine:

Manufacturer (name and country): ______________________

Model and reference: ______________________

Capacity (kg): ______________________

Nominal voltage (V): ______________________

Alternating Current? ☐ Yes ☐ No

Power (W): ______________________

Wash consumption @ 30^{o}C (kWh): ______________________

Wash consumption @ 60^{o}C (kWh): ______________________

Mean weekly use (time): ______________________

Dishwasher:

Manufacturer (name and country): ______________________

Model and reference: ______________________

Capacity (meals): ______________________

Nominal voltage (V): ______________________

Alternating Current? ☐ Yes ☐ No

Power (W): ______________________

Wash consumption (kWh): ______________________

Mean weekly use (times): ______________________

Other:

Type of appliance: ______________________

Manufacturer (name and country): ______________________

Model and reference: ______________________

Nominal voltage (V): ______________________

Alternating Current ? ☐ Yes ☐ No

Power (W): ______________________

Standby power (W): ______________________

Mean weekly use (times): ______________________

Q8 User satisfaction and adaptation to technology

Did the users seek the technology installed from a supplier or were they "pressured" into it? Please eleborate: ____________________

What was their reaction following commissioning?

- ☐ Completely satisfied
- ☐ Thankful
- ☐ Apprehensive
- ☐ Dissapointed

Has the new system improved their life style? Please eleborate: ____________________

Has the new system enabled them to do things they could not do previously? Please eleborate: ____________________

Has the new system assisted them to earn income? Please eleborate: ____________________

Do they perceive the new system as being cost effective? ☐ Yes ☐ No

What would their advice be to a friend proposing to invest in RE generation capacity? Please eleborate: ____________________

How well is the system performing?

- ☐ Better than expected
- ☐ As well as expected
- ☐ Not as well as expected
- ☐ A disaster from day one

Do they consider the system to be reliable? ☐ Yes ☐ No

To what extent are they responsible for system operation and maintenance?

- ☐ No involvement
- ☐ Assist as and when directed
- ☐ Regular operator responsibilities
- ☐ Periodic maintenance
- ☐ Responsible for all operations and maintenance