9. Appendix

Appendix 1 Questionnaire 04/98

IEA PVPS Task VII Act. 2.7 Reliability

Questionnaire

Please, prepare a paper summarizing the information available from your country on all incidents and effects, which disturbed the operation of a PV system.

Please specify,

How many incidents per system and year were observed ?

Which component was concerned ?

- modules
- inverters
- control unit
- peripheral equipment like wiring, connectors, diodes, fuses etc.
- mechanical construction
- anything else

What caused the incident ?

- design error (e.g. inadequate voltage or current rating of component)
- operational error (e.g. improper switching sequence)
- component failure
- careless or inappropriate labour
- lightning strike
- other

To **what extent the function** of the system was impaired (e.g., no function for 3 days, 50 % reduced output power, ...)

What repair effort was necessary

- repair by user
- by installer on-site
- by factory

Appendix 2 Questionnaire 04/01

Questionnaire

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please return this questionnaire by fax or email to

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email:
helau@ise.fhg.de

Name of your country:

On how many systems do You report? ....
(Please, mention only systems which you have confirmed information on)

What is range of the system size? .... kWp

And the average size? .... kWp

How many of these systems worked fine ever since commissioning? ....

For how many operational years these systems account? ....

Which components are used in these systems?
(Please, mention all brands and component types. Specify, in how many systems a component is used. If necessary add a separate sheet.)

Module			**Inverter**		
brand name	type	No. of systems involved	brand name	type	No. of systems involved

For the systems which did not operate satisfactorily:
(If available, add a list of concerned systems, stating name, location, size)

What are the reasons for non-satisfying operation? ....

....

....

....

How many incidents in how many systems in how many years were observed ?

.... incidents in .... systems in .... years

What is the average system size ? .... kWp

Which component was concerned ?	**How often ?**
- modules	
- inverters	
- control unit	
- peripheral equipment like wiring, connectors, diodes, fuses etc.	
- mechanical construction	
- other (please specify):	

What caused the incident ?	**How often ?**
- design error (e.g. inadequate voltage or current rating of component)	
- operational error (e.g. improper switching sequence)	
- component failure	
- careless or inappropriate labor	
- lightning strike	
- other (please specify):	

Appendix 3 Responses to Questionnaires

from

Canada

Germany

Spain

Sweden

Switzerland

The Netherlands

United Kingdom

United States of America

In this section of the appendix only those documents are presented, which are available as file in english language. More documents had been submitted as paper copy or in German language.

Canada

Reliability and Availability – The Canadian Perspective

1. RELIABILITY

At this time there are probably less than fifty utility interactive photovoltaic systems in Canada. The largest installation at the Hugh MacMillan Rehabilitation Centre comprises four systems totalling 80 kilowatts. The smallest installations feature individual AC modules rated at 100 watts. While this number of installations is not enough to give statistically meaningful results, the reliability experience with these systems seems to agree with published results from world-wide installations. When examining the reliability of utility interactive photovoltaic systems, one can focus almost entirely on one component, the power conditioner. The other components are largely passive. The following summarizes our limited experience with utility interactive photovoltaics in Canada:

Photovoltaic Array Support Structure

Support structures hold the photovoltaic modules in place; modules generally do not blow off the roof. The main concern for this component occurs in the original design. Photovoltaic arrays should be installed to ensure maximum solar exposure for the active photovoltaic area while at the same time minimizing wind loadings on the array surface. Also, for retro-fit of photovoltaic systems on existing buildings, the addition of the support structure on the roof should not compromise the structural integrity or weather seal of the existing roof.

Photovoltaic Modules

Photovoltaic modules produce electricity whenever the sun shines and if they perform well for the first year, they are likely to continue to perform for a very long time. So far, no system has been in operation longer than the expected lifetime of the photovoltaic module. If there is a future problem, it is likely to occur in the module junction box. This box is very exposed to the elements and mounted on the back of a glass surface, it experiences higher than ambient temperatures. Evidence of corrosion may show after ten to fifteen years of operation.

Reliability issues for photovoltaic modules relate almost entirely to vandalism and theft. Photovoltaic modules must by their inherent function be exposed. Also in the case of non-building installations such as street lighting, they are often located in isolated areas. They are therefore very vulnerable to damage by vandals. As the general public becomes aware of the uses of photovoltaic systems, the modules also become targets for theft. Vandalism and theft issues can only be minimized during the system design. Generally, the photovoltaic modules should be kept out of reach. They can also be installed with theft proof fasteners.

Electrical Components

Fuses, breakers and switches normally function as required and are likely to function according to specifications for the life of the photovoltaic systems. Their reliability may reflect their passive role as well as the maturity of the electrical industry.

Power Conditioner

Any system failures are likely to occur, and have occurred in the power conditioner. The quality of this unit is the key factor in determining overall system performance.

In today’s market, any utility interactive photovoltaic power conditioner larger than 25 kilowatts is likely to be custom designed. It may share features from other installations but it will definitely not be an established, mass produced product. Start-up problems, some more serious than others, can therefore be expected. Surprisingly, many of the start-up failures occurred in sub-components which are in fact

mass produced. These parts included a fibre optics receiver, coils in several output filters and a DC switch. Once these parts were replaced, the power conditioners worked well.
After up to seven years of operation, some power conditioners are experiencing failures, some resulting in self-destruction of the IGBT's in the bridge. The firing of these IGBT's is very sensitive to signals and the fault can usually be traced to the control board. Over the years, irregularities from the utility or lightning induced voltage spikes may have placed stress on the control circuitry causing faulty signals. Hopefully, as the industry develops it will develop better designs. Until that time, the system designer should place much importance on the attitude of the manufacturer. Some manufacturers show more willingness to service their product than others. Several years after installation, some manufacturers have reduced their work in photovoltaics, some have changed staff, and others are too busy. Since the power conditioners are complex, custom designed components, the user is very much dependent on the original manufacturer for service work.
Smaller power conditioners, that is those in the 1 to 5 kilowatt and smaller, back-of-the-AC module units will be mass produced. They should therefore have been thoroughly tested in the factory. With simple, straightforward installation, no start-up problems should be expected from these units. Nevertheless, the photovoltaic industry is relatively new and component designs are largely unproven. Failures have occurred with the smaller power conditioners, usually within several weeks of actual field operation. The problems can usually be attributed to control circuitry recently developed but lacking actual field experience. Failure to protect itself from utility irregularities or user abuse usually leads to destruction of the IGBT's or at best, failure of the control to bring the unit into operating mode. For these small power conditioners, the system designer should consider ease of unit removal, shipping to supplier and replacement until such time that the industry is able to supply a very reliable product.

2. AVAILABILITY

Unlike most other types of power supplies, there is no control over the output of utility interactive photovoltaic systems. They only produce power when the sun shines. The amount and distribution of solar radiation received over the average year is largely a function of geography. Whether a system in fact operates when it should is determined by many other factors. Availability can be described as the percentage of time the system is ready to operate independent of solar conditions. The key word is "ready".

Reliability plays a role in availability. As described above, if a device is broken, it will not run. Assuming there are no component failures, there are several other factors which determine whether the system is performing according to specifications. These should be discussed separately as availability issues.

Photovoltaic performance is greatly affected by shadows. In solar thermal installations, shadows on the collector will have a proportional effect on the thermal output. In photovoltaics, covering ten percent of a module can result in an eighty percent reduction in electrical output. Early photovoltaic installations were mostly stand-alone systems powering remote communications equipment, water pumps, etc. The emphasis was on performance of the power supply and designers went to great length to ensure maximum solar exposure for the photovoltaic array. With the development of building integrated utility interactive photovoltaic systems, there has been a shift to aesthetic issues and rightly so. No customer wants a science experiment tacked on his building. However, aesthetics should not compromise performance. An educated customer will not be happy to discover that his relatively expensive photovoltaic canopy just becomes a decoration after two o'clock every day. Many current installations, including IEA demosites, suffer from reduced availability due to shadow effects. Architects should therefore work with photovoltaic specialists to ensure that electrical performance is not compromised by other design concerns. Where shadow effects are unavoidable, there are electrical design solutions which can minimize the effect.

In northern climates a shadow related issue is snow cover. Since a photovoltaic module must be exposed to the sun, exposure to falling snow cannot be avoided. The issue therefore becomes how long the snow remains on the module. A very strong “selling feature” of photovoltaics is its low maintenance requirements. Manual snow removal for a photovoltaic array would therefore not be acceptable. Key factors in determining snow cover duration and related availability are array orientation, wind scouring effects and mechanical details such as frame profiles.

From an electrical perspective an important factor in determining availability has been fault parameters and auto restarts. The photovoltaic power conditioner is electrically connected to the utility. For safety as well as self-protection purposes, the power conditioner is programmed to disconnect from the utility during out-of-spec conditions. The unit will isolate itself should the utility voltage drop below a certain value for example. Setting the correct limits for voltage, current and frequency to ensure safe operation while limiting nuisance fault trips, is critical to maximizing system performance. Deciding which faults require manual restarts and which can be allowed auto restart will also have a significant impact on system availability. Recent experience has shown that many utility interactive photovoltaic systems were programmed with tolerances that were too tight. Field tests revealed that utilities could not maintain published voltage limits during peak demand periods. In some cases the limits for the power conditioners had to be lowered to reduce unnecessary shutdown of the photovoltaic system.
Photovoltaics is a relatively new technology. Building integrated systems connected to the utility is an even newer development. Ensuring maximum availability of these power sources and public acceptance of this technology will require designers to consider both architectural and engineering components of their systems.

Germany

The German 1000-Roofs-PV Programme – a Résumé of the 5 Years Pioneer Project for Small Grid-Connected PV Systems

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ABSTRACT: Within the framework of the German 1000-Roofs-PV Programme a total of 2056 grid-connected PV systems with a total output of 5,3 MW_p were installed on the roofs of private houses. All systems were subjected to a five-years measurement programme, 100 systems selected on a statistical basis were equipped with a special measuring system. Besides these long-term activities specific work has been carried out on the analysis for low energy yields, the inspection of PV-plants, sociological questions and architectural aspects. All work has been carried out in joint co-operation between Fraunhofer ISE Freiburg, FZ Rossendorf, ISFH Emmerthal, IST Energietechnik Augsburg, JRC Ispra (Italy), TÜV Rheinland Köln, Umweltinstitut Leipzig and WIP München.

Keywords: Small Grid-connected PV Systems - 1: Monitoring - 2: Qualification and Testing - 3

1. INTRODUCTION

Within the German 1000-Roofs-PV Programme 2056 grid-connected PV systems (about 5,3 MW_p) were installed on roofs of private houses. The Federal and State Governments, which had supported the installation of these systems from 1990 to 1995, aimed to achieve four goals. At first the use of roofs for electricity generation should have been harmonised with construction and architectural aspects. The second goal was to stimulate the users to save electricity and adapt their consumption to the rhythm of solar generation. The optimisation of all components and to gain installation know-how were the third and fourth major goals. A measurement and evaluation programme ("S-MAP"), in which all systems were subjected to a five-year monitoring period, was carried out in parallel (Fig. 1). Also, covering 3 years, up to 100 systems were equipped with special data acquisition systems ("I-MAP"). Specific tasks were the analysis of low energy yields, the inspection of PV systems, sociological questions and architectural aspects.

S-MAP and I-MAP have been carried out since 1992 by Fraunhofer ISE in co-operation with WIP, JRC and IST Energietechnik. ISFH was responsible for the reduced yield analysis and TÜV Rheinland conducted the system inspections in co-operation with FZR and IST. The measurement and analysis programme was headed by Fraunhofer ISE. The technical evaluation has been complemented by a sociological study, which Fraunhofer ISE carried out together with the Umweltinstitut in Leipzig. In addition 400 system operators participated in the competition of the "Most Attractive 1000-Roofs System". The results from the particular programme sections will be presented in a final scientific report, which will be available in late autumn 1998.

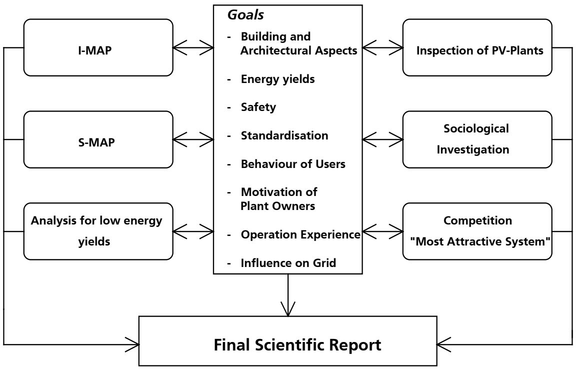

Figure 1: Measurement and Analysis Programme

2. SELECTED RESULTS OF THE MEASUREMENT AND EVALUATION PROGRAMME

At the end of the installation period (mainly until1995) 2011 systems with a total installed power of 5.3 MW_p were monitored. The average power within the programme is approximately 2.5 kW_p, the average value of the system costs about 24 DM/W_p (12 ECU/W_p). This high prize compared to the situation in the last years is due to the financing model. To prevent funding of arbitrarily expensive systems, an upper limit for actual system costs was set: 27,000 DM/kW_p.

About 50% of the PV systems are equipped with Siemens modules. The effect of opening the programme to modules from manufacturers of EC country led to an increasing market share of other manufacturers.

Concerning the inverter, SMA is dominant with a market share of nearly 50%. It can clearly be stated, that the programme gave a strong impulse for different inverter manufacturers for the development of new and improved inverter types with low power rating.

The energy produced by a typical 1000-Roofs-PV System is measured by the Annual Final Yield:

$$\text{Annual Final Yield} = \frac{\text{Inverter Output (kWh)}}{\text{Nominal Power of the PV array (kWp)}}$$

Fig. 2 shows the average annual final yield between 1992 and 1997 for all PV systems with complete data sets in the corresponding years.

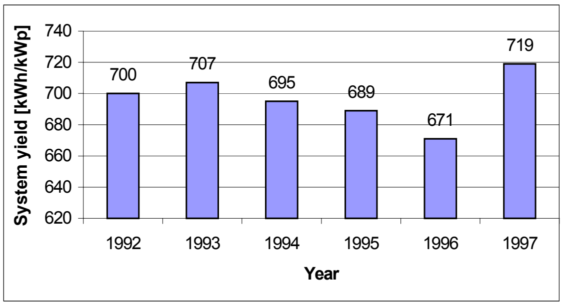

Figure 2: Average annual system yield from 1992 to 1997

The results show a small fluctuation around the average of 700 kWh/kWp. However, this can not give a general expectation value for the individual PV systems, since the distribution of the annual final yields is between 400 kWh/kWp and more than 1000 kWh/kWp. The main causes for the different energy outputs are as follows:

- different solar radiation conditions
- partial shading of the solar generator
- different quality and efficiency of system components
- system breakdowns.

Considering typical electricity consumption figures for Germany, a 2.5 kW_p PV system can provide about half of the annual electricity consumption of a four and more person household on the average. However, it seems difficult for the plant owners to adjust daily and seasonal energy consumption to PV production times, like the figures in Table I show. For systems with large solar fractions the direct consumption gets lower. The annual electricity consumption of 1000-Roofs households is not different from that of households without a PV system. According to corresponding statistics this amounts to 4700 kWh/a (for a four member household).

Table I: Average annual electricity consumption, solar fraction and direct consumption from 1993 to 1997.

Year	1993	1994	1995	1996	1997
Systems	684	1203	1332	1182	835
Consumption [kWh/a]	4857	4428	4525	4783	5150
Solar fraction [%]	47	52	53	49	53
Direct consumption [%]	47	46	46	47	48

According to the reports of the plant owners, 65% of the total number of failures was caused by inverter defects. Frequency and number of system failures decreased significantly during the project realisation thus proving the relevance of the 1000-Roofs-Project for the development of system technology (Fig. 3).

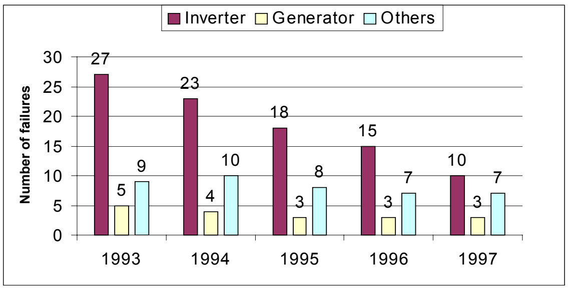

Figure 3: Reported failures per component (per 100 systems, considering PV systems with any data available for the corresponding year).

For 100 systems selected for I-MAP a uniform measurement data acquisition system was installed (Fig. 4).

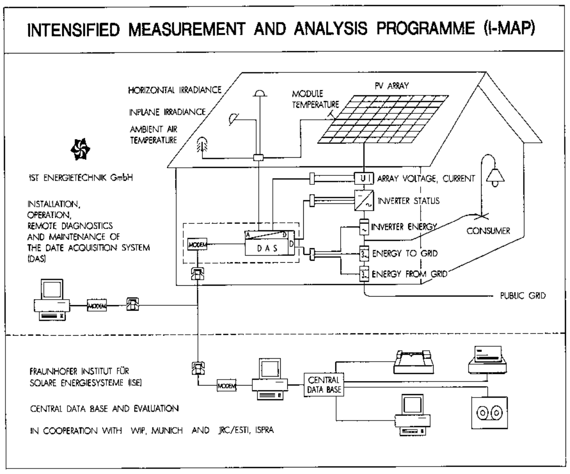

Figure 4: I-MAP Monitoring concept.

To assess the efficiency of the conversion of the solar energy irradiated, the performance ratio has to be calculated, where E_{PVuse} is the AC-energy output from the inverter [kWh], $E_{S,A}$ the total solar energy on array plane [kWh] and η_{STC} is the nominal array efficiency at Standard Test Conditions (STC).

$$PR = \frac{E_{PVuse}}{E_{S,A} * \eta_{STC}}$$

The performance ratio found for the I-MAP systems was between 55 % and 80 %. Half of the systems achieved a performance ratio exceeding 70 %. Problems registered in systems with performance ratios lower than 60 % were longer breakdown periods for the inverter, poor module performance, string breakdown and faulty plug-in connectors for solar roofing tiles. Investigations on the influence of the power ratio P(Inverter) / P(PV-Generator) (0.8 - 1.4 for the PV-systems investigated) on the performance ratio didn't show any dependence.

3. SYSTEM INSPECTION AND REDUCED YIELD ANALYSIS

Shortly after the installation of the first PV systems in the Federal States, TÜV Rheinland carried out technical inspections. In addition, after a system operation of several years further inspections have been done by TÜV Rheinland, FZR and IST. These inspections should provide information on time-to-failure, quality of installation, environmental influences, maintenance, user behaviour and on the stability and long-term behaviour of the components. 200 PV systems had been inspected by the end of 1997. ISFH was in charge of analysing the causes of very low energy yields in more detail.

Special PV systems analysers for in situ measurements of small grid connected PV systems were developed and successfully used by FZR and ISFH.

The system inspections revealed that some components (specified former as suitable) were questionable on the basis of the experience to date. One explanation for this is that the manufacturers were not (or were partly not) aware of the specific requirements within a photovoltaic D. C. system. For this reason, requirements for these components have been specified and verified by short term testing [4].

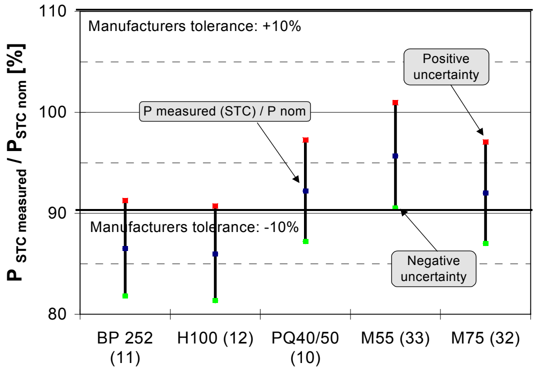

Figure 5: Mean deviation of operating power of various solar generators compared with the module nominal power for five typical module types.

The determination of the generator power at STC frequently revealed power deficits of 10 to 20% compared with the datasheet values given by the module manufacturers (Fig. 5). STC-power given in the data sheets could only be reached by two module manufacturers, for one type a general technological failure seems to become evident.

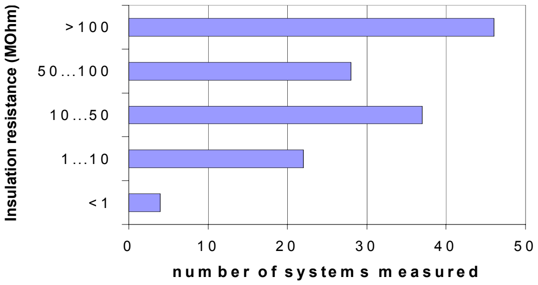

Figure 6: Insulation resistance of 137 PV systems.

Taking into account, that the PV generator power is lower than defined by the data sheets, revised performance ratios can be calculated ranging between 70 and 80% and being in good agreement with the theoretical estimations as well as results from large grid connected PV systems. Altogether, the detected deficiencies can be summarized as shown in Table II.

Table II: PV system defects and deficiencies indentified by inspections

Installation problems	
(Partial) Shading of the solar generator	41 %
Unsuitable string fuses and overvoltage shunts	15 %
Unsuitable insulation devices (Fig. 6)	56 %

Problems encountered during operation	
Moderate to strong soiling of the solar modules	12 %
Loose terminal connections	5 %
Corrosion and defects in the solar generator mounting	19 %
Solar generator cabling not mechanically fastened	24 %
Defect decoupling diodes	< 2 %
Lack of heat dissipation of decoupling diodes	60 %
Defect string fuses	4 %
Defect surge arrester	< 1 %
Faulty modules (broken glass, open circuits, discoloration)	< 2 %

Others	
PV system documentation incomplete	46 %

4. SOCIOLOGICAL STUDY

Within the 1000-Roofs-Programme, 1450 plant owners have been asked for their opinion and experience concerning different technical and non-technical aspects of the programme [5].

Only 3% of all respondents would not decide for a 1000-Roofs-PV system under the same circumstances again. Without any funding 8% would be ready to build up such a system. The major source of information for the technical and organisational questions during programme realisation had been the installers and technical journals. However, the means of information dissemination for the programme were quite unsatisfying, most participants in the programme got their information accidentally.

A large percentage of the plant owners run other renewable energy systems in parallel (45,8 % thermal systems, 6 % wind turbines). Almost all plant owner use energy efficient household appliances and realised other ways for energy saving (like insulation of walls).

5. ARCHITECTURAL ASPECTS

A competition “Most Attractive 1000-Roofs System”, where 441 plant owners participated sending pictures and further information on their systems, showed the successful combination of architectural design with technical pretensions for a lot of PV systems, especially for roof integrated generators (Fig. 7). However it became clear, that not for all houses this goal was achieved.

Figure 7: Winner of the competition “Most Attractive 1000-Roofs-PV system” (Bechtold).

6. SUMMARY AND OUTLOOK

The German 1000-Roofs-PV programme clearly lead to a technical, economic and scientific boost on grid-connected PV systems for living houses.

The total energy produced by those systems can cover a significant part of the total energy consumption of the households. Yet the mismatch between energy production times and energy consumption and a correlation in the irradiation level for larger areas require the global grid as energy “buffer”. Producing PV energy on a larger scale (e.g. utilising all available suitable roof areas) therefore would require measures for global energy management over wider areas. For the prognosis of total energy yields losses due to unavoidable shading especially in urban environments must be taken into account (up to 10..15%). About 75% of the annual yearly PV energy is produced between April and September.

Even though the interest and participation in the programme was overwhelming, the realised funding model induced inappropriate high specific system cost. One conclusion therefore is, that any funding in future should honour cost saving measures for the technology.

A high quality of system components and correspondence to the parameters given in the data sheets is the elementary basis for good system performance. From the experience got in the 1000-Roofs programme it can be recommended to establish better mechanisms for quality control at the manufacturers or with the help of independent enterprises.

To optimise energy output and lower the number of system failures emphasis must be put on a profound design and commissioning and therefore good knowledge of the installers and manufacturers. It can be recommended to do regular plant inspections after some years of operation. Affected trades must ensure long-term service and provision of spare parts (in some cases this is a problem even today!). Expected times for operation of 30 years and more are a must for a wide spread PV application in buildings.

The technical concept and the components for most of the 1000-Roofs-PV systems proved to be reliable and well operating. Even though there was a significant percentage of defects reported by the plant owners average energy losses resulting from these can be neglected. Simplified installation concepts (omitting blocking diodes and string fuses, lower number of strings and modules with higher power) could decrease failure probabilities and lower costs. Inverters with integrated plant monitoring and intelligent failure diagnosis are necessary in future.

To increase acceptance of PV at decision makers and house owners balanced system concepts taking into account technical, architectural and economic aspects must be offered. For such integral solutions ongoing co-operation between architects, technicians, scientists and affected trades is indispensable.

The German 1000-Roofs-PV Programme showed a way to effectively increase the number of running PV systems in a short time and revealed the large potential for PV not only from the technical point of view but also from the readiness of people. It gave strong impulses to industry and installation companies and lead to a significant improvement in system technology.

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Quality Assurance of PV-Facades and Test Procedures

IEA PVPS Task VII, PV Integration Concepts Workshop
Lausanne, 11th - 12th February 1999

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Contents

1 Introduction

PV systems in buildings are experiencing a growing level of acceptance amongst building constructors, architects and specialist planners. Beside the energy gained, aspects such as the optical design of the building or the substitution of conventional facades and roof systems by PV elements come to the fore.

Certain requirements are to be fulfilled by the PV systems regarding quality and durability in order to ensure the integration of the "new“ design elements into the building sector.

In the following, a general overview of the existing quality criteria will be given which have to be taken into consideration by the architects, respectively by the specialist planners, in the planning and design of PV systems. Furthermore the technical requirements given in the standards and regulations are also to be observed. Furthermore the building specific regulations of the respective countries are to be observed which as a rule place very different demands on the building components and constructions in the building sector.

2 Requirements of PV Systems

PV systems are to be seen as electrical installations independent of where they are installed (facade, roof, independent structures) and the safe operation of the systems is to be ensured through suitable measures. The architects and specialist planners are equally obliged to ensure such safety as are the companies installing the systems (metal construction companies, electrical installation companies, roofers). In the following table one can see the resulting requirements to be developed for PV systems.

Requirements	Considerations
Maximum energy yield from the PV system	• optimal alignment of the PV modules • shadow-free operation of the PV system • expert (qualified) lay-out/design of the electrical system (inverter, cabling etc.) • monitoring system for operation data/ failures
Physical construction requirements	• Thermal insulation (insulating glass for thermal facades) • Acoustic protection • Mechanical stability (areas with inclined glazing) • other relevant building regulations such as regulations for fire safety
Quality of system components	• Type approval of all used system components according to national and international standards
Safety during installation and operation	• no danger to persons may arise from PV systems (electric shock) • protection against electric arcs (risk through the DC-circuit) • the requirements given in IEC-364 are to be fulfilled • grid interface issues and safety regulations of the utilities are to be fulfilled

For the design and operation of electrical components and installations there are numerous international, European and national regulations and standards. A small selection are listed in Chapter 5, Standards and References.

When the architect or specialist planners compile tender documents then the requirements given in the regulations are to be described and later to be laid down in the delivery contract. It is recommended that proof be established of the system properties and characteristics by means of an acceptance test when the system is put into operation, which should be carried out by an accredited test institute such as TÜV Rheinland which is independent of the manufacturer.

3 Management Issues and Test Procedures

In the design phase it is of importance to put the system requirements into practise constructively and with regards to design. The installation companies are urged to carry out the installation and erection work in a qualified and quality-conscious manner. Guarantees are to be agreed upon with the installation companies. In the following, several recommendations will be given with which quality criteria for PV systems can be described.

3.1 Organisational Measures

In the planning and installation of larger PV facade systems the participants are, e.g., building constructors, architects, specialist planners, manufacturers, electrical installation companies and facade constructors. In particular in overlapping sectors (electro-facade construction) the work of the specialist companies is to be co-ordinated.

The regulations of the professional associations/ employers liability insurance are to be observed, which, for example, do not permit the execution of electrical installation work by electrical laymen. Furthermore the risk of touching electrically active components during installation work especially in the DC circuit is to be excluded by suitable measures. This PV specific problem of “no cut-off possibility“ in the DC array circuit is present when working on this circuits or in case DC-cabling is damaged for example through fire inside the building.

3.2 PV System Tests

The PV systems should be implemented and tested according to the following points:

- In accordance to utility regulations in order to ensure the conditions of the grid connection
- Detailed system documentation with lay-out and installation plans, information on maintenance and service
- Data recording for system balancing and performance control
- Acceptance and performance test of the PV-system and proof of adherence to the relevant regulations, in particular to IEC-364 (Electrical Safety)
- Detailed safety concept for operation of the plant and performance of maintenance work
- Safety isolation points in DC and AC circuits for the danger-free execution of assembly and repair work
- Electrical installation with Safety Class II - Equipment according to IEC-364-4-41

3.3 PV system components

PV Modules

- Proof of the type approval examination according to IEC 61215
- Proof of Safety Class II
- Performance guarantee longer than 10 years
- Utilisation of by-pass diodes to avoid hot-spot effects, or equivalent measures

Inverter

- Inverter marked with the CE-label
- Efficiency higher than 90%
- Guarantee of 2 years
- Proof of adherence to the grid connection conditions

Cabling and Other Components

- Module cabling with double insulation, UV resistant and suitable for temperatures up to 70°C
- Total cabling losses ≤ 1%
- DC components (switches, fuses) must be designed for the maximum system variables

3.4 Constructive Properties

The following general issues have to be taken under consideration.

- Sufficient mechanical mounting of the PV modules in the facade and roofs
- If necessary: waterproof design and integration into building envelope
- Manufacturer’s certification of additional properties, e.g. thermal insulation, fire safety behaviour, and static behaviour
- Sufficient rear ventilation of the PV modules

Furthermore the specific building regulations of the respective countries are to be taken into consideration.

4 Summary

PV systems are and will continue to be important design and construction elements in building technology. Of even more importance is that the quality properties of PV systems be secured, which are also to be seen with regard to the relatively high investment costs of e.g. PV facade systems.
Equally no danger to persons or other building installations (fire) may arise from PV systems.
Beside careful specialist planning, a qualified installation of the PV system is to be ensured, It is recommended that the relevant system features be verified by an independent test institute on the basis of an acceptance test.
Marking PV building products (including mounting structures or facade profiles) with the CE label would increase the possibility for architects to plan accordingly and would exempt them from receiving a permission for the building through an individual act by the construction authority.
However for CE marking the existence of harmonised European standards or a European technical approval is necessary. Future activities will be required in order to make standardised PV building products available in Europe.

5 Standards and References

- IEC 364: "Erection of power installations with nominal voltages up to 1000 V“
- IEC 364-4-41: "Protection against electric shock“, 01-1997
- EN 50110-1, 1995: "Operation of electric installations"
- IEC 61215: "Crystalline silicon terrestrial photovoltaic modules - design qualification and type approval“, 1993
- IEC 1730 C:, 1998-02, “PV-Module safety Qualification Testing“ (Committee Draft)
- IEC 1194, 1996-12, “Overvoltage protection for PV power generating Systems- Guide“
- IEC 1727, 1995, “PV-systems - Characteristic of the utility interface“
- prEN 1187-1:1993, “External fire exposure to roofs“, this document specifies a method to determine the resistance of roofs to external fire exposure.
- ISO 3009:1976, Fire resistance test - glazed elements
- national standard in Germany: DIN 4102-1, Behaviour of building materials and components in fire; building materials; definitions, requirements and tests
- Construction Products Directives (CDP) 89/106/ECC 10.08.1992
- Low voltage directive 73/23/EEC
- Electro Magnetic Compatibility directive 89/336/EEC
- Status of the Qualification of PV Systems and Components - Qualification Strategies, Test Experiences, TÜV Rheinland, paper for the 2nd World PV Conference and Exhibition, Vienna, July 1998

Spain

REPORT

THE IES PV GRID CONNECTED BUILDING: IEA QUESTIONNAIRE

0. SYSTEM CHARACTERISTICS

PV Array:

Nominal Power, according to manufacturer: 14.5 kWp

3 separate fields:

1. Terrace (-8º oriented, 20º tilted), 7.3 kWp of Isofoton modules (M-88, of 88 Wp each, manufacturer value)
2. Façade (-8º oriented, 35º tilted, optimum angle for Madrid), 5.3 kWp of BP Solar modules (BP495, of 92 Wp each, manufacturer value)
3. Tower (-8º oriented, 5º tilted), 0.5 kWp of Isofotón module (M-50, of 50 Wp each, manuf. value)

All modules were submitted to quality control, which gives an actual nominal power for the whole PV Array of 13.5 kWp

Inverter:

Rated output power: 12 kVA

Triphasic equipment, IGBT technology, a prototype at the purchase time

Voltage source-type

Automatic DAta Adquisition System: complies with the JRC-Ispra Monitoring Guidelines (analytical monitoring)

Security:

PV Array electrical configuation: floating

All metallic parts (supporting structures, modules frames, shields, etc) grounded

Inverter has an isolating transformer

2 overvoltage protection circuits for the DC side:

- At the PV Array level: 3 surge suppressors between the + pole & earth, the – pole & earth, and between the + & - poles.
- At the input of the inverter. Here, too, there are 3 levels of protection: 3 surge suppresors like the ones mentioned above, a varistor and a Zener diode.

A voltage relay is installed in the AC Connection Box

A frequency relay is included in the inverter

An external security switch, of restricted use of the utility, is placed outside the building.

A contactor is governed by the voltage relay and the external security grid: only if both say “O.K”, will current flow into the grid.

System operation since December 94 (still working)

1. INCIDENTS:

The main incidents concern the inverter, what is very much explained by the fact that it was a prototype at the time of purchase, and because it acts a voltage-source, which makes the equipment very much sensible to grid perturbations (this is, in fact, a problem in our grid: it belongs to the Telecommunications University High School, where a lot of laboratories, computers, and so on, exist, which as you well know,demand a lot of current harmonics). The problems deal mainly with disconnections of the inverter from the grid, which had unequal durations ranging from 2 minutes to several hours. These happen more often in sunny days than in cloudy/rainy ones. In some cases (about 6 times / year) disconnections came from main circuit breaker to the grid, which meant that reconnection of the inverter to the grid had to be manual. Also 2 power stages (the IGBT bridge) had to be changed in 1996 and 1998 (one stage changed in each year).

Also we have detected twice problems with the connections between modules in both main fields (Terrace and Façade). These suffer from thermal induced mechanical stress (very high temperatures in summer; cold in winter), which loosed 2 branches.

No problems with security (fault errors, lighting overvoltages) ever ocurred.

2. ERROR CAUSE

Inverter:

Design error (a voltage source isn't the most appropiate design: this was one of the lessons for the inverter manufacturer)

Component failure: 2 times, the IGBT bridge failed and had to be changed.

PV Array: Thermal induced mechanical stress in some strings.

3. TO WHAT EXTENT WAS THE FUNCTION OF THE SYSTEM IMPAIRED?

Inverter eventual disconnections: from 2 minutes to several hours
Inverter activation of the Power Magnetotermic Switch: until it was noticed by the personnel in charge of the maintenance (the IES staff).
Inverter breakdown (power stages): between 7 and 30 days.

PV Array contacts loosened: until the loosed contact was detected (15 days in the worst case, the case of the Terrace: there are 90 modules and all contacts had to be checked).

4. WHAT REPAIR EFFORT WAS NEEDED?

Inverter activation of the Power Magnetotermic Switch: mannual activation of the Switch.
Inverter breakdown (power stages): Manufacturer operations.

PV Array contacts loosened: fastening of contacts, done by the personnel in charge of the PV system maintenance.

REPORT

INCIDENTS AND EFFECTS WHICH DISTURBED THE OPERATION OF THE PROJECT " BUILDING INTEGRATION OF A GRID CONNECTED PHOTOVOTLAIC SYSTEM WITH HIGH QUALITY ENERGY SUPPLY" - SE/242/94 ES

Inverter:

It was also found out that the procedure that controlled the Maximum Power Point Tracking (MPPT) needed to be readjusted. The range of voltages allowed before starting to look for a new working point was so wide that the inverter could remain in the same point for variations in the photovoltaic power of more than 20 kW. This range was reduced and this way the problem was solved

Data adquisition system:

The functioning of the monitoring system has been correct: there has only been data loss due to power failure in the building where the system is placed. In those cases, the data stored in the datalogger were lost. In order to avoid it, an Uninterrupted Power Supply (UPS) was installed, so as to filter short power outages. After the installation, only one data loss has been registered, and the reason for it is thought to be the duration of the outage, which was longer than the autonomy of the UPS.

Improvement of the software for data acquisition (which had already been installed in 1996). The improvement consisted basically in the resolution of the arising problems: some mistakes on control signals and logic; correction of some symbols that were not suitable on the presentation diagram...

Calibration adjustment of the sensors and converters used for measuring in the monitoring system. The signals involved in the adjustment were P_{TU}, P_{FU}, and P_{IO}.

Sweden

• Questionnaire

please return this questionnaire by fax or email to helau@ise.fhg.de	Hermann Laukamp Fraunhofer ISE D- 79100 Freiburg Oltmannsstr. 5 fax: +761 4588 217 email:

Name of your country: Mats Andersson, Sweden

On how many systems do You report? 4
(Please, mention only systems which you have confirmed information on)

What is range of the system size? 1.4, 2.1, 10,0, 50 kWp

How many of these systems worked fine ever since commissioning? 3

For how many operational years these systems account? 3.5 - 15 years

Which components are used in these systems?
(Please, mention all brands and component types. Specify, in how many systems a component is used. If necessary add a separate sheet.)

• ***Module***			• **INVERTER**		
brand name	type	No. of systems involved	brand name	type	No. of systems involved
ARCO	ASI 16-2000	1	Helionetics (*)		1
Kyocera	PSA 100H-361H	1	Sunny Boy 850		2
Solarex	Millenia MST-43MV	1	Sunny Boy 2000	transformerless	1
NAPS	NM 110	1			

(*) The Helionetics inverter was used 1986-2000 and was still working OK when we changed it last year to the new developed inverter Sunny Boy 2000

For the systems which did not operate satisfactorily:
(If available, add a list of concerned systems, stating name, location, size) Bad performance for the Solarex 10 kWp installation at IKEA

What are the reasons for non-satisfying operation? The production of the new a-Si Millenia modules was not

tuned and it was a bad product that was installed on the façade of the IKEA office 1997. The performance of this
system suffers from mismatching mainly.

How many incidents in how many systems in how many years were observed ?

approximately 10 incidents in ....4............ systems in ....15........ years

What is the average system size ? 16 kWp

Which component was concerned ?	How often ?
- modules	2
- inverters (in a former installation "Ringen" we had a lot of problems with Solcon!)	2
- control unit	
- peripheral equipment like wiring, connectors, diodes, fuses etc.	1
- mechanical construction	
- other (please specify): monitoring equipment	1

What caused the incident ?	How often ?
- design error (e.g. inadequate voltage or current rating of component)	
- operational error (e.g. improper switching sequence)	
- component failure	4
- careless or inappropriate labor (opening inverters outdoor when raining)	1
- lightning strike	
- other (please specify): bad product (Millenia) or vandalism (modules broken)	2

Switzerland

Questionnaire

please return this questionnaire by fax or email to

Hermann Laukamp
Fraunhofer ISE
D- 79100 Freiburg
Oltmannsstr. 5
fax: +761 4588 217
email:
helau@ise.fhg.de

Name of your country: Switzerland

- Please see the additional Excel sheet!!

On how many systems do You report? 8
(Please, mention only systems which you have confirmed information on)

What is range of the system size? 13.5- 86.5 kWp

And the average size? 40 kWp

How many of these systems worked fine ever since commissioning?

4

For how many operational years these systems account?

From 8 - 3

Which components are used in these systems?
(Please, mention all brands and component types. Specify, in how many systems a component is used. If necessary add a separate sheet.)

• ***Module***			• **INVERTER**		
brand name	type	No. of systems involved	brand name	type	No. of systems involved

For the systems which did not operate satisfactorily:
(If available, add a list of concerned systems, stating name, location, size)

What are the reasons for non-satisfying operation? ....

....

....

....

How many incidents in how many systems in how many years were observed ?

.... incidents in .... systems in .... years

What is the average system size ? .... kWp

Which component was concerned ?	**How often ?**
- modules	
- inverters	
- control unit	
- peripheral equipment like wiring, connectors, diodes, fuses etc.	
- mechanical construction	
- other (please specify):	

What caused the incident ?	**How often ?**
- design error (e.g. inadequate voltage or current rating of component)	
- operational error (e.g. improper switching sequence)	
- component failure	
- careless or inappropriate labor	
- lightning strike	
- other (please specify):	

Switzerland

No	Name	Modules	Power	Modules operation since	Trouble to modules	Inverter type	Number of inverters	Inverter operation since	Inverter failures	Other trouble
	Pilot- Installations									
			[kW] S.T.C.							
1	Sheds Halle Génie-Civil	Solarex	11,8	1992	no	Solcon 3400	3	1993	4	DC fuses changed (replaced by higher values)
2	Brise-soleil	Solution-BP	3,2	1992	no	Siemens 3 phases	1	1992	1	AC fuses changed (replaced by delayed fuses)
3	Dép. des Matériaux - EPFL	BP Solar	5,2	1994	no	SMA PV-WR 5000	1	1994	1	
4	Laboratoire des réseaux électriques - EPFL	Flabeg-Telefunken	3,0	1994	no	Topclass 3000 GRID	1	1994	0	
5	Bâtiment d'Enseigement et de Services	Solution-Kyocera	1,4	1994	no	Solarmax 3000	1	1994	0	
6	EL-H, dép. d'électricité, LEME	Kyocera/Photowatt	10,0	1997	no	Sunways 5000	2	1997	1	
	DEMOSITE pavilions									
7	Sofrel	Photowatt	0,6	1997	no	TOPCLASS 4000 GRID III	1	1997	0	
8	Amax	Siemens	0,6	1997	no					
9	Ecofys	Shell / BP Solar	1,1	1997	no					
10	Solbac	Siemens	0,9	1997	no					
11	Powerlight	Siemens	0,8	1997	no					

12	Solgreen	Photowatt	0,9	1999	no	TOPCLASS 2500 GRID II	1	1996	0	
13	Solmax	ASE	1,2	1999	no			1994		
14	Solrif	Fortum	1,2	1999	no	Topclass 1500 GRID	1	1992	1	
15	EPV	EPV (formerly APS)	1,1	1992	no	SMA PV-WR 1800	1	1993	1	
16	Braas	Pilkington	0,7	1998	small delamination modules replaced	Topclass 1500 GRID	1	1992	1	
17	Uni-Solar	Uni-Solar	1,1	1992	no	Topclass 1500 GRID	1	1992	1	
18	Shadovoltaic	GSS-Astropower	1,0	1992	no	Topclass 1500 GRID	1	1992	1	
19	IT Power	BP Solar	0,6	1996	no	Sunny Boy 700	1	1996	0	
20	MSK	Solarex	2,5	1995	no	Topclass 2500/4 GRID	1	1995	2	
21	Pil-Sim	Fabrisolar	1,9	1999	no	Topclass 1500 GRID	1	1992	1	
22	Sunny Tile	Star Unity	0,9	1996	no	SMA PV-WR 1800	1	1993	1	
23	Shell Solar	Shell Solar	0,4	1999	no	AC modules	1	1999	0	
24	Atlantis	Sunslates	1,6	1997	no	SMA PV-WR 1800	1	1993	1	
	Total		**53,5**							

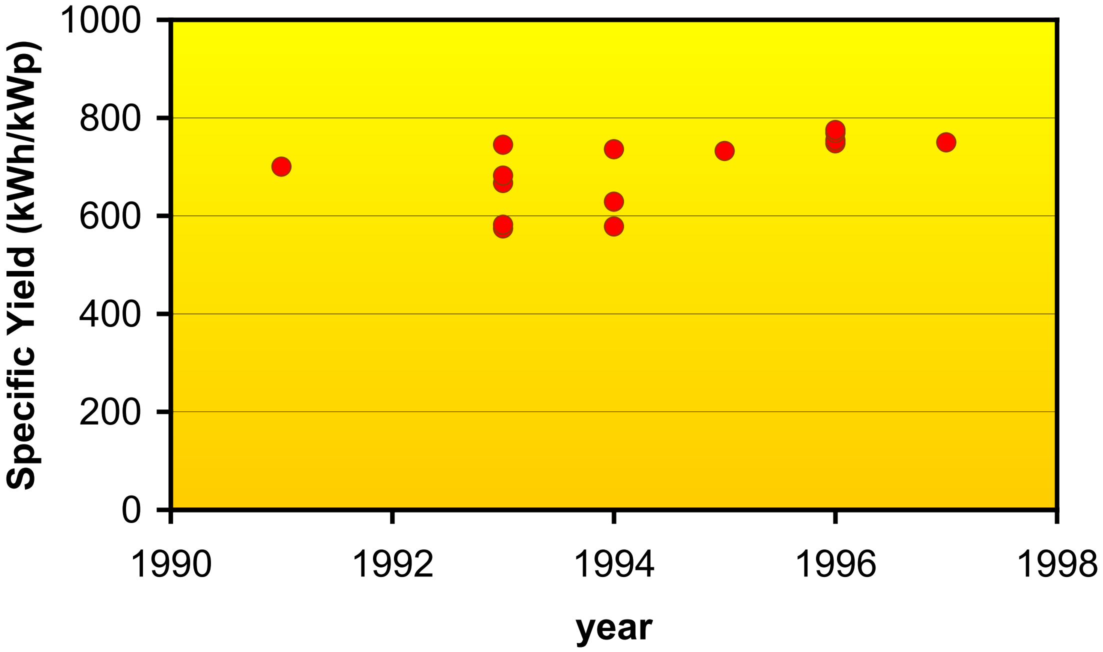
Remark:: Inverters are often reused and thus older than modules !

The Netherlands

Operational Experiences from PV in the Netherlands

The figure below shows the climatological yield of a number of systems monitored in the Netherlands in the period 1992 – 1997. The systems have varying tilt angle and orientation, although most of them are optimized quite well in this aspect. None of the systems have significant shading. All systems are based on crystalline silicon technology-modules. From the figure, a few things can be learned:

- Judging from the upper values per year, the maximum achievable performance of the systems has hardly increased.
- In the earlier years more systems with suboptimal performance were realized.



The best systems have a performance ratio of about 0.75. This seems to be a line that is hard to cross. Examples of improvements that have taken place in this period is improvement in inverter efficiency and reliability of the systems, especially inverters. It should be noted that the reliability of inverters is not shown in the figure, because yearly yields are usually corrected for system outage.

Although improvements have been made, inverter availability remains an item of concern for the future. It is also expected that more systems with non optimal orientation and shading will be placed in the future, as the systems move from the demonstration phase into the market place. This might have a negative effect on average yearly yield of the systems. Usually corrected for in these figures.

The data from this figure is provided in the overview on the next page.

system	Type of system	Year of Constructio	Yklim (kWh/kWp	Low yield	Reference
Heerhugowaard	DC wired system	1991	700		J.H. Boumans, A.J.N. Schoen, C.W.A. Balthus, R.C.J. van Zolingen, T.C.J. van der Weiden, "Overview and Performance of Gridconnected PV-systems in The Netherlands; Proceedings of the 13th European Photovoltaic Solar Energy Conference, H.S. Stephens & Associates, 1996; pp 2437 - 2439
Heino	DC wired system	1993	574	degraded single junction a-Si	E.C. Molenbroek, F. Leenders, A.J. Kil, "Monitoring van een amorf silicium PV-systeem te Heino", rapport Ecofys E2044, juni 1999
Woubrugge	DC wired system	1993	667	partially shaded	J.H. Boumans, T.c.J. van der Weiden, "Monitoring dakgeïntegreerd PV-systeem in Woubrugge Eindrapportage" Ecofys E249 oktober 1995
Bezemer, Lekkerkerk	DC wired system	1993	582	inverter not optimized	Boumans, J.H., Weiden, T.C.J. van der, "Monitoring van een 3 kW PV-daksysteem in Lekkerkerk", rapport E270, Ecofys, november 1995
ONS Schiedam	DC wired system	1993	682	partially shaded	M. Schalkwijk, A.J. Kil, T.C.J. van der Weiden, "aanvullende analyse van meetresultaten van de 10 kWp systemen bij EDP, ONS en ECN, ecofys E234, 1996
ECN Petten	DC wired system	1993	745	partially shaded	M. Schalkwijk, A.J. Kil, T.C.J. van der Weiden, "aanvullende analyse van meetresultaten van de 10 kWp systemen bij EDP, ONS en ECN, ecofys E234, 1996
Leiden, Zonnewende	DC wired system	1994	578	partially shaded	W.O.J. Böttger, J.H.N. Boumans, T.C.J. van der Weiden, "Analyse van drie 2.3 kWp PV-systemen in gerenoveerde woningen aan de Zonnewende te Leiden", Ecofys E 2008, december 1996
Leiden, Zonnewende	DC wired system	1994	629		W.O.J. Böttger, J.H.N. Boumans, T.C.J. van der Weiden, "Analyse van drie 2.3 kWp PV-systemen in gerenoveerde woningen aan de Zonnewende te Leiden", Ecofys E 2008, december 1996
Zandvoort	DC wired system	1994	736		J.H. Boumans, A.J.N. Schoen, C.W.A. Balthus, R.C.J. van Zolingen, T.C.J. van der Weiden, "Overview and Performance of Gridconnected PV-systems in The Netherlands; Proceedings of the 13th European Photovoltaic Solar Energy Conference, H.S. Stephens & Associates, 1996; pp 2437 - 2439
Amersfoort SCW systeem 2a	DC wired system	1995	732		H. Marsman, A. Kil, T. Schoen, L. Bader, "Monitoring van netgekoppelde PV-systemen SCW in de Wijk Nieuwland Amersfoort", rapport ecofys E2031, december 1998.
Arthur Andersen	AC modules	1996	748	partially shaded	A.J. Kil, E.C. Molenbroek, "Monitoring PV-systeem kantoor Arthur Andersen Amstelveen-resultaten 1998", rapport E2118, Ecofys maart 2000
dak Ecofys (Sun-master 130S)	AC modules	1996	754		L.E. de Graaf, T.C.J. van der Weiden, "Monitoring PV-systeem van 20 AC-modules", rapport Ecofys E2045, oktober 1995
Nieuw Sloten, Sunmaster1800	DC wired system	1996	769		A.J.Kil, M. van Schalkwijk, H. Marsman, T.C.J. van der Weiden, "Monitoring PV systeem Nieuw Sloten", ecofys E 2004 mei 1999
School De Border, Amersfoort	AC modules	1996	775		Molenbroek, E.C., K.J. Hoekstra, T.C.J. van der Weiden, AC-module Pv systems in Italy, Portugal and the Netherlands, E 2075, Ecofys, Utrecht, november 1999
PV prive ENW/EDON	AC modules	1997	750		de Wit, B., M. van Schalwijk, A.J.N. Schoen, "Globale monitoring van AC-modules in het PV-privé project van ENW Amsterdam en EDON", rapport E2053, Ecofys, Utrecht, februari 1999

United Kingdom

The attached spreadsheet shows the installations done by Solar Century to date.
All systems have been operating without problem since installation.

We have a variety of monitoring strategies;

1. We pay a rate based incentive for exported kWh to domestic customers to account for the difference between the utility export rate (no 99pfennig offer in the UK) and the German rate. This gives us political lobbying and operational information as the client must send in their generation, import and export figures.
2. Some clients have Sunny Boy Controllers installed and send us graphs as well as monitoring for their own interest.
3. Government funded contracts have very detailed monitoring requirements (as per the old Thermie requirements) and this data will be used by the contract managers.
4. Our commercial clients all have service agreements whereby we either carry out periodic inspections or (preferably) we set up the system to send us an alarm signal if there is a fault.

So far the only system errors (apart from problems identified on installation and commissioning) have been caused by non-system parameters:

1. Grid out of bounds. Where the utility supply is regularly outside the G77 (under and over frequency and voltage) parameters, the inverters spend too much time in standby mode.
2. Operator error. This has happended only with the standalone system using the Trace inverter. The user was 'playing' with the settings and managed to set the system to default so the PV diesel hybrid no longer functioned. I had to give instructions over the telephone at midnight from a bar in London to our client working by the light of a candle in Scotland to restore the settings and get his system operating!!

All of our systems are less than 2 years old (apart from the United Solar shingles) and operational time is not yet critical.

Dr Daniel Davies
Director of Engineering
Solar Century

	Chart 6: Solar Century Installations										
	Name	**Location**	**Type**	**kW**	**Date Installed**	**Connect -ed**	**# days connected**	**KWh/ a**	**kWh to date**	**Kg CO2 saved**	**Comments**
1	Raleigh Road	Richmond, Surrey	Grid-connect	1.6	Feb 99	2.1.99	1277	1 200	4 198	2 939	1st UK solar rooftile shinglesinstallation
2	Mindrum Farm	Nr Coldstream	Stand-alone	2.1	Okt 99	10.1.99	1035	1 575	4 466	3 126	PV & diesel back-up system to supply farm
3	The Old Bakehouse	Cholsey	Grid-connect	1.6	Jan 00	1.17.00	927	1 200	3 048	2 133	1st UK Sunslates installation
4	Carol Howard	Hertford	Grid-connect	1.2	Jan 00	2.7.00	906	950	2 234	1 564	
5	Bovis (Cheltenham & Dist HA)	Whitminster, Nr Stroud	Grid-connect	1.05	Feb 00	3.16.00	868	788	1 873	1 311	Solar thermal and PV
6	Bovis (Cheltenham & Dist HA)	Whitminster, Nr Stroud	Grid-connect	1.05	Feb 00	3.16.00	868	788	1 873	1 311	Solar thermal and PV
7	Begbrooke	Materials Lab, Oxford Uni	Grid Connect	6.1	Feb 00	3.1.00	883	4 575	11 068	7 747	Test array comprising 11 PV technologies
8	Nottingham Uni	Nottingham	Grid-connect	1.6	Mrz 00	6.13.00	779	1 200	2 561	1 793	Eco House on campus
9	RIBA	Living City Exhibition, London	Grid-connect	1.68	Apr 00	4.1.00	0	0	0	0	Temporary - demonstration for exhibition
10	Genoa Avenue /Shocket	Putney, London	Grid-connect	2.88	Mai 00	5.4.00	819	2 160	4 847	3 393	SC's first roof integrated laminate system
11	Pontin	Chew Magna	Grid-connect	3.4	Mai 00	5.15.00	808	2 550	5 645	3 951	UK's biggest sunslates installation
12	Westall/ Bromley	Park End, Bromley	Grid-connect	1.0	Mai 00	5.5.00	818	750	1 681	1 177	
13	The Old Chapel	Penzance	Grid-connect	1.44	Jul 00	7.26.00	736	1 080	2 178	1 524	Most westerly grid connected PV system
14	Layton / Devonshire Road	Forest Hill, London	Grid-connect	1.68	Sep 00	9.11.00	689	1 260	2 378	1 665	
15	Sainsburys	North Greenwich, London	Grid-connect	6.75	Okt 00	10.11.00	659	5 063	9 140	6 398	SC's first commercial installation
16	Glen House	Innerleithen, Scotland	Grid-connect	10.2	Okt 00	2.23.01	524	7 680	2 756	1 929	UK's 1st Private Solar Electricity generator (1)
17	Queens Lodge Ecohouse	Muswell Hill, London	Grid-connect	2.0	Nov 00	1.10.01	568	1 500	2 334	1 634	Free standing array in garden
18	Ohio / Orange	Hatfield	Grid-connect	1.13	Nov 00	12.1.00	608	846	1 409	986	SC's 1st glass laminate installation
19	Fletcher	Fordingbridge, New	Grid-Support	3.4	Nov 00	3.1.01	518	2 550	3 619	2 533	SC's 1st grid-support system

		Forest									
20	Rushmore Borough Council	Farnborough	Grid Connect	0.96	22. Mar 01	4.16.01	472	720	931		
21	Chris Lowe	Canterbury	Grid Connect	2.2	26. Mar 01	4.1.01	487	1 650	2 202		
22	Laings	Edmonton, North London	Grid Connect	14	Jan 01	4.23.01	465	10 500	13 377		DTI 100 Roofs - 1st proj with developer for private sale
23	Maidenhead & District HA	Maidenhead	Grid Connect	20	Jan 01	4.30.01	458	15 000	18 822		DTI 100 Roofs
24	Thomas Foster	Colchester	Grid Connect	4.0	01. Apr 01	5.1.01	457	3 000	3 756		
25	Fiona Adams	Birmingham	Grid Connect	1.8	09. Apr 01	4.27.01	461	1 350	1 705		
26	Texaco	Roehampton, London	Grid Connect	10.4	in April 01	4.15.01	473	7 800	10 108		
			TOTALS:	**89.1**				**65 584**	**102 639**	**47 116**	

Notes: Dates are given in MM.DD.YY.
Reference date for energy production is April 30, 2001

	Name	Manufacturer	Astro-Power	BESS	Atlantis	St Gobain	Utility	Inverter
			KWp	KWp	KWp	KWp		
1	Raleigh Road	BESS		1.6			Seeboard	3 x Sunny Boy 70 inverters
2	Mindrum Farm	AstroPower	2.1				N/A	Trace 4548E
3	The Old Bakehouse	Atlantis			1.6		Southern Electric	Sunny Boy SWR1100
4	Carol Howard	Astropower	1.2				Eastern Energy	Sunny Boy 850
5	Bovis (Cheltenham & Dist HA)	AstroPower	1.05				MEB	Sunny Boy SWR700 * 2
6	Bovis (Cheltenham & Dist HA)	AstroPower	1.05				MEB	Sunny Boy SWR700 * 2
7	Begbrooke	8 different ones	0.55	0.55			Southern Electric	Sunny Boy 700 * 5 + OKE *36
8	Nottingham Uni	Atlantis			1.6		Midlands Electrecity	Sunny Boy SWR1100
9	RIBA	AstroPower	1.68				London Electricity	NKF OK4E
10	Genoa Avenue /Shocket	AstroPower	2.88				London Electricity	Sunny Boy SWR1100 * 2
11	Pontin	Atlantis			3.4		Western Power Distribution	Sunny Boy SWR1100 * 2
12	Westall/ Bromley	AstroPower	1.0				London Electricity	Sunny Boy SWR700
13	The Old Chapel	AstroPower	1.44				Western Power Distrib - East Elec Solarnet	2 x Sunny Boy SWR700
14	Layton / Devonshire Road	AstroPower	1.68				London Electricity	2 x Sunny Boy SWR700
15	Sainsburys	AstroPower	6.75				Sainsburys in-house local power generation CHP	5 x Sunnyboy SWR850
16	Glen House	BESS		10.24			Eastern Energy - Solarnet	4 x Sunny Boy 2500
17	Queens Lodge Ecohouse	AstroPower	2.0				Eastern Energy - Solarnet	2 x SMA SWR700
18	Ohio / Orange	Atlantis		1.128			Eastern Energy	1 x Sunny Boy SWR1100E
19	Fletcher	Atlantis			3.4		Eastern Energy - Solarnet	2 x Sunny Boy SWR1100E + Trace DR1524
20	Rushmore Borough	BESS		0.96			Scottish and Southern	2 x Sunny Boy SWR700

	Council							
21	Chris Lowe	AstroPower	2.2				Eastern Energy - Solarnet	1 x Sunny Boy SWR700, 1 x Sunny Boy SWR1100E
22	Laings	Atlantis			14		Eastern Energy - Solarnet	12 x Sunny Boy SWR700
23	Maidenhead & District HA	AstroPower	20				Eastern Energy - Solarnet	8 x Sunny Boy SWR1100E + 7 x Sunny Boy SWR2500
24	Thomas Foster	AstroPower	4					1 x Sunny Boy SWR2500
25	Fiona Adams	AstroPower	1.8					2 x Sunny Boy SWR700
26	Texaco	BESS		10.4			London Electricity	4 x Sunny Boy SWR2500
		TOTALS:	**45.6**	**14.5**	**24**	**0**	84.1	

United States of America

US Response to IEA PVPS Task VII Subtask. 2.7 Reliability Survey

As US technical representative to IEA Task 7, I am responding to the questionnaire regarding reliability of BIPV systems. This is an issue which is of concern to the US PV community.

However, we see the reliability issues of BIPV system closely related to the same reliability issues with all PV systems. There is considerable work already completed and standards already in place here in the US relative to reliability of PV modules.

All BIPV components to sold into the US market will need to meet these existing standards. These include IEEE 929 and 1262 and UL 1703. These standards include specifics on electrical safety, long-term reliability and resistance to environmental factors.

The performance of BIPV components in place of conventional building materials such as facade or overhead glazing, for example, is addressed under the provisions of the standard building codes for these materials.

We do not anticipate the widespread development of new standards specific to BIPV applications here in the US. Instead, we see a gradual evolution or modification of existing standards to incorporate provisions specific to BIPV where they may be required.

The US is interested in following the work and can contribute copies of the existing US codes and standards for your review and use. We do not anticipate the development of any new standards here specifically for BIPV in the near future.

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2) Prepare a paper summarizing the information available from your country on all incidents and effects which disturbed the operation of a PV system.

please specify,
How many incidents per system and year were observed ?

The exact number is not known but the total has been very small. In nearly all cases, the system failure has involved the inverter. There have been very few recorded instances when a system failure caused a serious problem such as a fire or endangerment of personnel.

Which component was concerned ?

- modules
- inverters
- control unit
- peripheral equipment like wiring, connectors, diodes, fuses etc.
- mechanical construction
- anything else

The modules have proven to be the most reliable of all components that make up a PV system. The inverter has proven to be the least reliable. Occasionally wiring and diode problems occur but at this time they are rare.

What caused the incident ?

- design error (e.g. inadequate voltage or current rating of component)
- operational error (e.g. improper switching sequence)
- component failure
- careless or inappropriate labor
- lightning strike
- other

At this time, 98% of all PV system failures in the US are the result of inverter failure. The US Government's DOE PV program is investing R&D funds to improve inverter reliability. Lightning occasionally does cause problems for PV system and most often effects the inverter. In stand-alone systems there have historically been problems with battery charge controllers. These have been more to do with improper set up upon system commissioning as opposed to a component failure. If the charge controller isn't set up properly to work with the specific battery selected a the temperature of the site, premature battery failure will result. This has too often been the case in years past.

To **what extent the function** of the system was impaired (e.g., no function for 3 days, 50 % reduced output power, ...)

The best statistical sample would be from the Sacramento Municipal Utility Districts internal records of operation. They have fielded many hundreds of roof-top systems in their service area and many are monitored. SMUD has been reluctant to release details of these records as it could reduce the level of upper management support for the solar program. I do know that in past years there have been many failures - with the vast majority attributable to inverter failure. I also know that the inverter manufacturers have worked closely with SMUD engineers to make the necessary repairs as their future business depends upon it. The inverter is and will continue to be the cause of the majority of PV system failures.

What repair effort was necessary
- repair by user
- by installer on-site
- by factory

Very seldom is the user qualified or authorized to do on-site repair. Occasionally, the installer can make a repair on-site but most often the inverter must be removed by the installed and sent back to the factory. In cases where the trouble was caused by components other than the inverter, the installer usually makes repairs at the site, usually by replacing the offending component.

Appendix 4 Safety Relevant Failures in Photovoltaic Systems

1. Introduction

The electrical characteristics of solar cells are such that, under unfavourable circumstances, defects and errors can lead to major damage (e.g. fires), or danger to persons. Especially in systems with high voltages and/or high currents, even small errors can strongly jeopardise safety. However, such events usually represent the final stage in a development, during which smaller defects or incidents occurred but generally were not noticed. The most critical type of error constellation is that which does not trip a fuse but can lead to a dangerous contact voltage or creation of an electric arc. In order to avoid such error constellations, initial incidents must be recognised, which form the beginning of a chain leading to damage or danger. These critical situations can have various causes, such as component design defects, material fatigue, degradation of system components, moisture penetration or installation errors.

This report identifies and presents such primary causes, which occured in practice and which, if avoided, would significantly increase the safety of photovoltaic systems. It is based on experience in operating mainly larger photovoltaic systems, which has been documented in writing and, in most cases, published. Table 1 provides an overview of the systems for which relatively detailed information on operating experience and incurred faults was available. In these systems, either the entire solar generator field was examined carefully in detail, or faults and damage had been closely investigated immediately after their occurrence.

The operating age of these systems varies widely, from two to fifteen years, which plays a role when the defects are analysed and the identified faults are prioritised. For instance, some of the revealed component defects have already been eliminated by manufacturers' improvements or modifications in the construction.

Table 1 Systems with available information

No.	name	remarks	power [kW$_p$]	inauguration	reference
1	Kobern-Gondorf (Germany)	several types of modules	340	1988	/4, 5/
2	Neurather See (Germany)	several types of modules	350	1991	/4, 5/
3	Neunburg (Germany)	several types of modules	370	1990 - 1995	/5/
4	Toledo (Spain)	several types of modules	1 000	1994	/2, 5/
5	Serre (Italy)	several types of modules	3 000	1994	/6/
6	Vulcano (Italy)		80 0	1984	/1/
7	several large plants (USA)	summarising report	n.a.	n.a..	/7/
8	3 small systems (USA)		3 - 8 0	1980 - 1983	/3/
9	PHALK Mount Soleil (Switzerland)	1000 V Voc	500	1992	/8/
10	various residential systems	investigation under the 1000-roofs programme	1....5	1993-1997	/10/
11	barn (Switzerland	detailed analysis available	3	-	/11/
12	Mönchaltdorf, residence (Switzerland)	private communication from P. Toggweiler	3	?	/13/
9	Sky Harbour (USA)	tracking system	200 kW	1982	/9/

2. Defects Affecting Safety

2.1. Modules

As far as the modules are concerned, the standard today is generally high. In particular, moisture penetration, which led to insulation faults in older models and sometimes to a low-resistance short circuit to ground, has now been effectively eliminated on a long-term basis. The durability of the new, frameless large modules in this respect cannot yet be evaluated. In one system with amorphous silicon modules, there were considerable problems with the insulation, so that most of these modules had to be replaced /1/. No significant problems have been observed among the other more recent systems to date.

The damage and defects in modules which occurred to a notable extent are restricted to certain module types. With one module type, the cell connectors broke or became disconnected as a result of the high thermal loads experienced by the modules in operation. The faults in the cell interconnects frequently led to formation of an electric arc and to fire damage of the module or to glass breakage /5/. As this fault did not occur with other module types, evidently weaknesses in the design or the manufacture were decisive.

At least two module types failed with excessive ground leakage currents, when employed in high voltage systems (>=350 V). In one case the insulation between the connecting wires from inside the module to the junction box and an aluminium foil in the module backsheet degraded quickly after the modules were fielded. Another module showed increased earth currents during humid weather conditions. These faults sometimes developed into open arcs /4/.

In both cases the manufacturers redesigned their modules and removed the flaw.

These ground faults often caused complete destruction of the module and posed the hazard of starting a fire.

Junction boxes

Much more frequent sources of faults and damage than the photovoltaic modules themselves were the module connection boxes (j-box). Problems with moisture, or water penetration during heavy rainfall, were found most frequently. This led to insulation defects and corrosion of the connections, terminals and diodes, which sometimes resulted in a fire in the module junction box (figure 1). Most of these faults are caused by poor installation practises (inadequate sealing, wires lead into j-box from top -see figure 2).

However, ambient conditions often lead to condensation of water and thus to corrosion of the connections and diodes./1/,/4/,/7/. In fact, it is well known in standards for electrical equipment for outdoor use that a provision to drain condensation water must be provided /12/. Equipment exposed to direct sunlight heats significantly above ambient temperature. Air spaces assume this temperature. Simultaneously air carries a certain amount of water which corresponds to the relative humidity. In fact, the vapour content of air at a given value of relative humidity increases strongly with temperature.

Thus, under insolation j-boxes contain air of a certain humidity. At night this air cools down and the vapour condenses leaving plain water drops in the junction box.

This effect takes place everywhere, except for desert areas, where the air is extremely dry and even at night the dew-point is not reached.

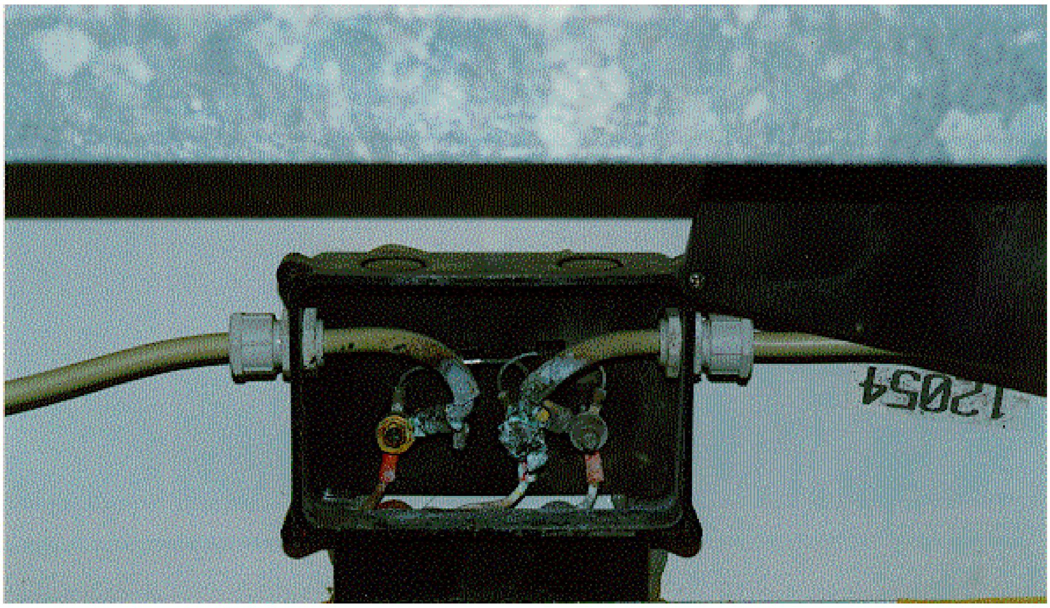

Figure 1: Damaged junction box; Apparently water penetrated and could not drain. It caused corrosion of contacts virtually disabling the module.

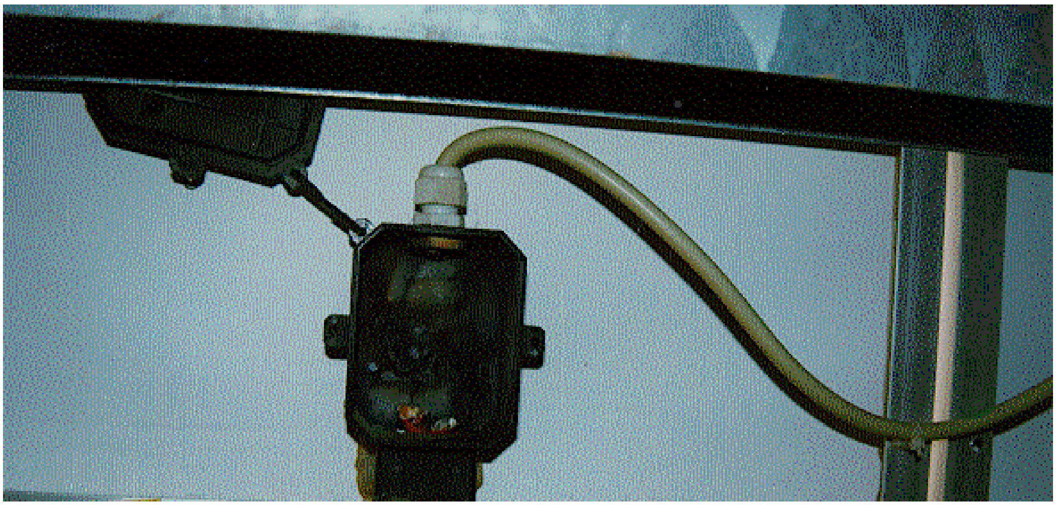

Figure 2: Wire from the top leads water into the j-box. The interior had been destroyed by an arc.

Another cause of damage is presented by loose or broken connections. These seem to be caused mostly by poor workmanship during installation. However, these defects can be caused by high thermal cycling, which work the screwed connections loose with time. In some cases broken PCBs in J-boxes were reported, which also caused arcing across the interruption /6/. Depending on the circumstances, these errors can lead to arc formation and destruction of the module connection boxes.

The by-pass and string diodes are further potential sources of damage /7/. Some diodes failed due to failing soldering connections. Defect diodes (short-circuited or disconnected) do not immediately present a danger but, combined with other faults or specific operating conditions (e.g. partial shading), can result in damage to the modules (e.g. hot spots). Diode breakdowns can be caused - apart from internal faults - by overvoltages induced by lightning strikes, as occurred in one system /4/.

The amplitude of the overvoltage caused by lightning in a module field depends on the design and circuit configuration of the module field; large loops favour the appearance of critical overvoltages. The comments above on connections also apply to the diodes; loose or broken connections to the diodes can cause further damage, just as when the diodes themselves are defect.

In some cases, major damage resulted from the combination of a number of smaller faults, each of which initially remained undetected /7/. Here, the US practise of grounding seems to have detrimental effects on system reliability . It actually seems to increase the probability of ground faults.

2.2. Switch gear

There are individual cases where unsuitable switches, power relays and components to protect against overvoltage were sources of error. One residence burnt down , most likely due to an improper circuit breaker /11/. An AC circuit breaker could not interrupt the string current in a 160 V system. An arc developed and incinerated the casing, which was not self-extinguishing. Consecutively, the casing set its environment , a straw storage, afire.

In a large plant again a circuit breaker did not interrupt the 1000 V, 35 A subfield current and an arc damaged the cabinet /8/.

In one system, the resistance of the varistors was found to have been reduced /6/, in another case, varistors caused a fire in the switchbox /7/.

Inspections under the !000-roofs programme revealed loose terminals in connection boxes at about 6 % of the inspected systems /10/. Modules were hardly checked due to inaccessibility. No follow-up incident was reported. We assume that this is explained by the rather low system voltages - 50V ... 160 V - used throughout this programme. The inspections revealed a lack of fixation of the string wiring in 20 % of the inspected systems, a high risk for future ground faults from abrasion /10/. In 12 % of the systems improper string fuses or overvoltage protection were reported.

Few faults or damage affecting safety are known to have originated from inverters. Once, a connections had been loosened by vibration /2/,. In a second case an inverter input terminal became overheated after it became loose /13/. Luckily, no further damage occurred.

3. Analysis and Consequences

The reported faults and damage affecting safety can be classified into two categories with regard to their causes. On the one hand, there are faults in the modules and module junction boxes which arise from poor design or manufacture. However, the manufacturers have learned from experience in the field and have made improvements, so that the number and extent of faults in newer systems has been reduced.

The second category of potential error sources includes weaknesses in the construction or installation and circuit design of the entire system. Above all, care should be taken in choosing a suitable connection technique (soldered connections are evidently critical), in making the connections and in controlling the seals around the terminals and cable entries. Further, suitable elements and system components (diodes, switches, circuit breakers, fuses, overvoltage protectors) should be carefully chosen for stability under the considerable stresses and durability under the specific operating conditions. Finally, the circuit configuration and the geometrical layout of the modules affect whether external influences such as lightning, or defects in the diodes or connections, can lead to further and more significant damage.

3.1 Recommendations

- use class II installation equipment
- prefer spring loaded „cage clamp“ terminals
- always introduce cable from below
- avoid soldered connections
- provide drainage for condensation water
- verify the dc rating of switches , circuit breakers, fuses
- control pressure and torque for screw terminals on printed circuit boards

Literature

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/13/ P. Toggweiler, private communication

Appendix 5 Experiences with 30 Stand-Alone PV Hybrid Systems

Paper presented at: 2nd World Conference on Photovoltaic Solar Energy Conversion, 6 - 10 July 1998, Vienna, Austria

LONG-TERM OPERATING EXPERIENCE WITH THIRTY STAND-ALONE PHOTOVOLTAIC SYSTEMS

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ABSTRACT
Grid-independent photovoltaic systems with battery storage and an auxiliary diesel generator supply electricity to remote hikers' inns, mountain huts, private houses, isolated farms and other buildings in locations all over the world.

Fraunhofer ISE alone has planned, in some cases installed and/or provided measurement support for thirty stand-alone photovoltaic systems throughout Europe [1]. To date, most of the long-term analyses of these systems have concentrated on energy aspects and the achievable efficiency values.

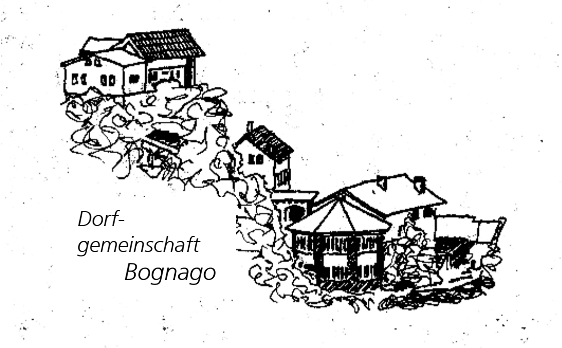
These long-term investigations demonstrate that the systems are functional, but like every technical system, they require service and maintenance. The broad statement, that stand-alone photovoltaic systems are free of maintenance, is true practically only for the solar generator. All the other components require - depending on the maturity of the system and the demands on reliability - repairs, post-installation improvements, regular maintenance work or replacement at intervals from five to ten years (e.g. batteries).

Within the project on "Quality assurance of photovoltaic energy supply systems", which is supported by the BMBF (German Federal Ministry of Education, Science, Research and Technology), the maintenance demand is determined, analysed and reduced as far as possible.

1. Introduction

1.1 Project Participants

Table 1 gives an overview of all 30 objects participating in the project.



Dorf-gemeinschaft Bognago

Bayreuther Hütte

Watzmannhaus

name of the object	in operation since	user/ heath over sealevel	back-up system	PV power [kW$_p$]	battery capacity [kWh]
Bayreuther Hütte	1995	DAV[1]/1600	diesel	2.4	48.0
Brunnsteinhütte	1990	DAV/1560	rape oil	0.9	12.0
Freiburger Hütte	1993	DAV/1931	diesel	5.0	52.0
Hexensee Hütte	1997	DAV/2576	—	0.9	24.0
Hildesheimer Hütte	1992	DAV/2899	diesel	4.0	38.4
Mindelheimer Hütte	1991	DAV/2058	diesel	5.4	49.0
Klostertaler Hütte	1993	DAV/2400	—	0.6	7.2
Oberreintalhütte	1995	DAV/1525	water	1.0	14.4
Purtschellerhaus	1990	DAV/1692	diesel	1.55	14.0
Ramolhaus	1994	DAV/3006	gasoline	1.0	28.8
Rotwandhaus	1992	DAV/1765	diesel/ wind	5.0	64.0
Stüdl Hütte	1996	DAV/2801	cogenerator	3.4	96.0
Tannheimer Hütte	1995	DAV/1760	—	1.1	24.0
Watzmannhaus	1992	DAV/1930	diesel	5.0	32.0
Westfalenhaus	1993	DAV/2273	diesel	1.0	15.8
Tegernseer Hütte	1996	DAV/1650	gasoline	0.8	19.2
Adrion	1996	farmhouse	cogenerator	17.1	67.0
Brotenau	1993	priv. residence	diesel	3.2	26.0
Bognago (Dorfgem.)	1991	priv. residence	diesel	4.3	32.0
Bwh. Frenz	1993	priv. residence	gas	1.0	12.0
Grünhütte	1993	hikers inn	diesel	4.9	52.0
Kaysersberg	1995	priv. residence	gas	2.4	18.0
Bwh. Langer	1991	priv. residence	diesel	1.8	19.0
Laufenburg	1994	hikers inn	gas	4.5	32.0
Rappenecker Hof	1987	hikers inn	diesel	4.8	32.0

---

[1] DAV - German Alpine Club

Roth-Grunert	1995	priv. residence	diesel	5.1	29.0
Unter-krummenhof	1992	hikers inn	diesel	4.5	32.0
Stein	1993	farmhouse	cogenerator	4.9	32.0
Talhof	1989	priv. residence	gas	1.8	26.0
Teufelsmühle	1995	hikers inn	diesel	11.5	115.2

Tab. 1: Overview of all 30 stand-alone PV objects

More than half of them are lodges and huts belonging to the German Alpine Club (DAV), which, with a few exceptions, are used only during the summer months. The spectrum encompasses small systems to provide light for unattended huts and larger systems for lodges with permanent staff and an average electricity demand of 0.1 kWh/d to 40 kWh/d.

All of the other systems operate throughout the year. Here, the palette ranges from private residences through hikers' inns to fully operational farms, with a corresponding variation in the average electricity consumption from 0.3 kWh/d to 60 kWh/d.

Within both groups of systems, there is a wide bandwidth in dimensions, so that annual solar fractions between 30 % and 85 % were achieved.

1.2 Work Programme

In order to gain reliable experience and knowledge of the maintenance work required, selected photovoltaic systems are inspected regularly. To this purpose, Fraunhofer ISE has prepared inspection manuals and has carried out a few sample inspections itself. All other inspection work is carried out at the operator's cost, by local firms wherever possible, with the help of the inspection manuals. In order to establish contractual ties between the operator and the maintenance firm, a generally accessible maintenance contract was written in close cooperation with the partners.

Drawing on the information entered into the inspection manuals and the log books kept at each system, Fraunhofer ISE analyses causes of fault, prepares statistics on interruptions to operation, determines the average probability of breakdown and the optimisation requirements of individual components and the entire system. In those systems where it proves to be necessary, improvements are made, optimised components are installed and/or the operating management improved, at the operator's cost.

2. Results

2.1 Data Base

To date, 22 of the observed systems, with a total of 116 operating years, have been included in the investigation of operating faults. Altogether 361 faults, most of them independent of each other, have been registered and classified, i.e. the data base is substantial. The oldest system, the Rappenecker Hof, has now been operating for more than 10 years, and in common with about a third (8) of the systems, is equipped with the Fraunhofer ISE five-voltage system, with an inverter which generates the 230 V AC voltage from five different DC voltages /2/. This means that in these systems, five essentially independent systems are installed next to each other, which differ only in the system voltage, so that all DC components are present fivefold. One of these systems was subsequently modified and now operates - like the second group (6) of investigated systems based on it - with the same five-voltage inverter. However, the different voltages are generated from a single system voltage by a DC/DC converter installed before the inverter input (this specifically developed DC/DC converter is included with the inverter in the discussion of fault modes).

In particular, the prototypes of the systems just discussed were clearly research objects, which were intensively supported, and in which newly developed components were tested and improved. In order to maintain comparability within the group and to the third group (a further 8), which consists primarily of smaller and simpler units with a system voltage of 24 or 48 V, it must be observed that about 100 of the 361 registered faults are directly related to research work.

This results in an average frequency for operating faults of

3.1 faults per system and year including research activities, 2.3 faults per system and year without research activities.

2.2 Classification of Fault Types

Each individual fault was evaluated with respect to the extent of damage to the affected component itself, essentially determined by the effort required to eliminate it. Further, the extent to which the fault restricted overall operation was assessed, a factor which is very significant to the operator, beyond the disturbance of the fault itself. A question on the cause of each fault was also asked.

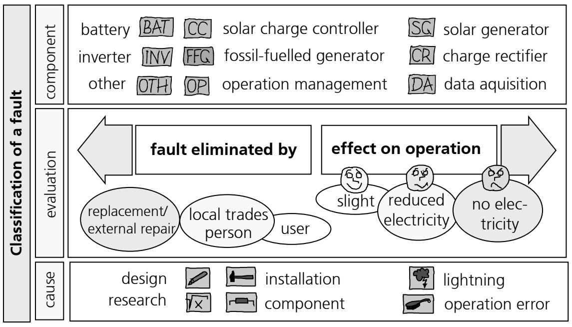


Fig. 1: Overview of structure to classify and evaluate a fault

2.3 Average fault frequency of the individual components

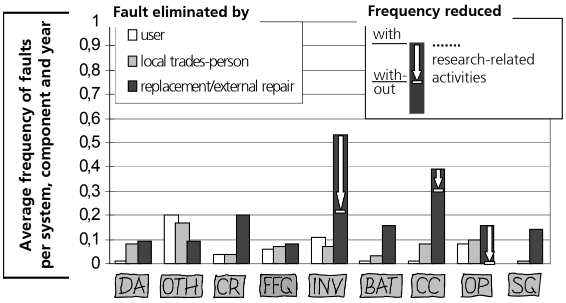


Fig. 2: Average frequency of faults (abbreviations, see fig. 1) per system component and year.

Exclusion of faults which are directly related to research leads to only a few but then very clear reductions, which are indicated in the graph with arrows in the appropriate bars.

Thus, the replacement frequency for the inverter decreased on average from about every two years to only once every five years. The reasons for a reduction in inverter faults have already been discussed in section 2.1.

Similarly, the number of malfunctions in solar charge controllers and operation management, which could not be repaired locally, was also reduced. Because the operation management switches (bi-stable relays) produced relatively often malfunctions when used with charge controllers for high system voltages in combination with the Fraunhofer ISE inverter, most of these have already been replaced by optically coupling switches and potential shifts have been eliminated. Thus, in most cases the cause of faults has been eliminated as a result of the most recent operating experience and is classified as "research-related".

The replacement interval for the solar generator (which also includes replacement of individual modules) of less than 10 years according to the graph is not representative, as about half of the systems investigated were equipped with the same type of module from a particular production series, which developed failures after four to five years [3]. The results for the "data aquisition" category must be interpreted with similar caution, as not only simple AC electricity meters but also sensitive systems for intensive measurements are included in the calculation.

The distribution according to the effort required to eliminate a fault is about equal for each total of the two variants "with" and "without research-related faults": in about 20 % of the cases, the user can eliminate the fault (usually after advice by phone), whereas in all other cases a specialist had to go to the system, with the repair finally being replacement of the component in three of four cases. Those faults which the user could eliminate are mainly found in the "other" category, which includes simpler tasks such as changing a fuse or switching the complete system off and on again.

2.4 Effects on Operation and Identification of the Cause of Fault

In total, about half of the faults led to a noticeable restriction in the power supply, the remaining half was hardly noticeable for the user.

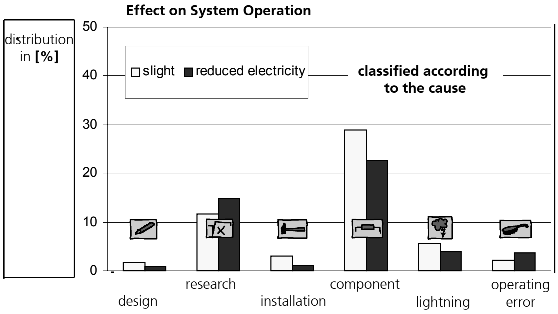


Fig. 3: Distribution of system operation restriction according to intensity and causes.

It is pleasing to note that hardly no fault led to a complete system breakdown. This is due to the deliberate duplication found in almost all systems, namely the photovoltaic system on the one hand and the fossil-fuelled generator on the other, so that an emergency power supply is guaranteed as far as possible.

System faults are most frequently caused by faults in individual devices. These are due to a wide variety of causes, e.g. the effect of lightning or operating errors. However, as can be seen in fig. 3, these "external causes" are seldom responsible for device faults. These are primarily due to aging-induced component defects, which are thus classified in the "component" category. The research-related activities follow with the second highest frequency.

2.5 Development over the Operating Period

In general, one expects to find a higher frequency of faults shortly after taking a system into operation and again toward the end of the individual component lifetimes, if a system is observed over many years. This pattern can be confirmed only for a few systems (see fig. 4).

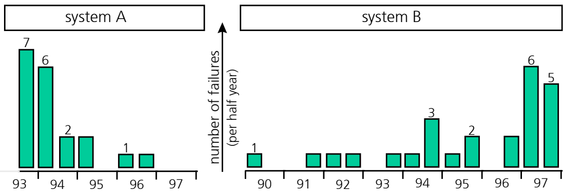


Fig. 4: Examples for a concentration in the fault frequency soon after commissioning (system A) and at the end of component lifetimes (system B) - number of faults per half year.

In many systems, there was not any noticeable reduction in faults after commissioning, i.e. there is still potential for technical development to reduce the fault frequency.

3. Summary

The average fault frequency of two occurrences per system and year (without including research-related activities) still appears to be very high, but can be expected to decrease with the increasing reliability of components such as inverters and charge controllers.

In order to identify and eliminate faults, a simple system check in spring and an inspection in autumn are recommended.

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