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Operational Performance, Reliability and Promotion of Photovoltaic Systems

Proceedings of October 2001 Workshop

PVPS

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

Report IEA–PVPS T2-03:2002

Operational Performance, Reliability and Promotion of Photovoltaic Systems

Proceedings of October 2001 Workshop

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Cover photographs:

upper left 16 kWp grid-connected PV system “Badeinsel Steinhude” in Germany. Photograph courtesy of Elektrizitätswerk Minden-Ravensberg (EMR)

lower right 20 kWp grid-connected PV system “Yatsusugi Training Center” in Japan. Photograph courtesy of New Energy and Industrial Technology Development Organization (NEDO)

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FOREWORD

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

The IEA Photovoltaic Power Systems Programme (PVPS) is one of the collaborative R & D Agreements established within the IEA. Since 1993, the PVPS participants have been conducting a variety of joint projects in the application of photovoltaic conversion of solar energy into electricity.

The mission of the Photovoltaic Power Systems Programme is “to enhance the international collaboration efforts through which photovoltaic solar energy becomes a significant renewable energy source in the near future”. The underlying assumption is that the market for PV systems is gradually expanding from the present niche markets of remote applications and consumer products, to the rapidly growing markets for building-integrated and other diffused and centralized PV power systems.

The overall programme is headed by an Executive Committee composed of one representative from each participating country, while the management of individual research projects (Tasks) is the responsibility of Operating Agents. By the end of 2001, nine Tasks were established within the PVPS programme, of which one was completed in 1997 (Task 6) and two were completed by the end of 2001 (Task 5 & Task 7).

The overall objective of Task 2 is to improve the operation and sizing of photovoltaic power systems and subsystems by collecting, analyzing and disseminating information on their technical performance and reliability, providing a basis for their assessment, and developing practical recommendations for sizing purposes.

This report contains the proceedings of the workshop “Operational Performance, Reliability and Promotion of Photovoltaic Systems”, organized under the supervision of IEA–PVPS Task 2 and held on the occasion of the 17th Photovoltaic Solar Energy Conference and Exhibition in Munich, Germany, on 24 October 2001. The report expresses, as nearly as possible, the international consensus of opinion of the PVPS experts on the subjects dealt with.

The full report may be obtained from the website *http://www.task2.org* or from the Operating Agent at a price of 10 EUR.

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ABSTRACT AND KEYWORDS

In recent years, national and international demonstration programmes in the field of photovoltaics have been initiated to develop typical market segments and to enhance technology progress. Gathering direct experiences of the feasibility, reliability and operating costs of PV systems is an important aspect of various implementation programmes. Evaluation programmes create a great deal of collected information on technical and non-technical issues, but only a portion is published and available. The International Energy Agency (IEA) Photovoltaic Power Systems Programme (PVPS) represents an attempt to highlight common achievements and problems, and to promote recommended practices.

As part of the IEA–PVPS programme, Task 2 is collecting and analyzing operational data of PV plants in various types of systems (grid-connected, stand-alone systems, hybrid systems) spread all over the world. This work has been carried out to gather experiences and results of both technical and economical performance, for the promotion of PV. It aims at gaining an increased understanding of the operational performance, energy behaviour, characterization and design of photovoltaic systems, subsystems and components. In addition, performance analysis is a crucial element in the learning cycle of design - installation - monitoring - evaluation - and the improvement of the system design.

This report summarizes the operational performance results of PV systems drawn from the performance analysis of different PV systems located in 12 IEA countries. The issue of reliability of PV plants and components is presented and included.

The report also covers the Task 2 Performance Database, which contains high quality data of 316 monitored PV plants with an installed peak power of 10.8 MWp and which can be obtained from Operating Agent of Task 2 or downloaded from the Task 2 website.

Addressing electricity utilities, the report concludes with the benefits of using PV power systems and gives successful examples of utility programmes to promote PV installation and PV electricity use.

Keywords: added values, array efficiency, availability of PV system, built environment, buy-back rates, database, electricity utilities, evaluation, green power products, grid-connected systems, irradiation losses, large PV systems, maintenance, monitoring, national programmes, net metering, normalized presentation, operational experiences, operational performance, performance analysis, PV components, reliability, sizing, stand-alone PV systems, utility programmes.

APPROACH

Workshop Background

The workshop entitled “Operational Performance, Reliability and Promotion of Photovoltaic Systems” was organized as part of the IEA–PVPS programme. The workshop was held under the auspices of Task 2 (Operational Performance, Maintenance and Sizing of PV Systems) of this programme. Representatives from the following countries participating in Task 2 prepared the workshop programme: Austria, France, Germany, Italy, Japan, Netherlands and Switzerland. Germany was the coordinating country through Projekttraeger Juelich (PTJ). PTJ commissioned Ulrike Jahn (Institut für Solarenergieforschung GmbH Hameln/Emmerthal) and Wolfgang Nasse (Solar Engineering Decker & Mack GmbH) to prepare, execute and report on the workshop.

In preparation for the workshop, the Task 2 members identified the experts in their countries working on operational performance issues of PV power systems. A screening of the experts identified and the work done so far by these experts resulted in a list of topics that were addressed by the workshop. The workshop objectives were formulated and approved by Task 2 members, and a workshop programme developed with the topics to be addressed.

Workshop Objectives

The overall aim of this workshop is to provide updated information and tools, which will help to improve and promote PV systems and components. The workshop objectives are as follows:

- Review / overview of issues regarding operational performance and reliability of PV power systems;
- Provide a tool (Performance Database) for PV system performance analysis;
- Identify maintenance efforts for large PV power systems;
- Identify reliability issues of PV systems and components;
- Clarify understanding of irradiation on PV systems in the built environment;
- Define the performance of stand-alone PV systems;
- Identify benefits offered by distributed PV energy generation for utilities.

The workshop was targeted at both professionals (PV industry, small and medium enterprises, electric utilities) and visitors to the exhibition, who benefited from involvement with a group of international experts working on the analysis and improvement of PV system performance.

ACKNOWLEDGEMENTS

The authors of the report would like to thank the speakers from Austria, France, Italy, Japan, the Netherlands and Switzerland for their comprehensive contributions in the form of presentations and papers, and for making this workshop possible.

We would further like to thank the Task 2 members who helped to prepare and actively supported the event.

Our thanks also go to the Operating Agent of Task 2, Reinhard Dahl, for his supervision and support for this workshop. In particular we are grateful to Mr Thomas Nordmann for his valuable comments in the preparation phase, for his moderation of the workshop programme and for his technical support in executing the workshop.

This work has been executed within the framework of the Implementing Agreement of the International Energy Agency‘s Photovoltaic Power Systems Programme.

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1 INTRODUCTION

1.1 IEA–PVPS overview

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD) which carries out a comprehensive programme of energy cooperation among its member countries. The European Commission also participates in the work of the IEA.

The IEA Photovoltaic Power Systems Programme (PVPS) is one of the collaborative R & D Agreements established within the IEA. Since 1993, the PVPS participants have been conducting a variety of joint projects in the application of photovoltaic conversion of solar energy into electricity.

The overall programme is headed by an Executive Committee composed of one representative from each participating country, while the management of individual research projects (Tasks) is the responsibility of Operating Agents. By the end of 2001, nine Tasks were established within the PVPS programme, of which one is not operational (Task 4), one was completed in 1997 (Task 6) and two were completed by the end of 2001 (Task 5 & Task 7).

The 21 PVPS members are: Australia, Austria, Canada, Denmark, European Union, Finland, France, Germany, Israel, Italy, Japan, Korea, Mexico, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom and the United States.

The mission of the Photovoltaic Power Systems Programme is “to enhance the international collaboration efforts through which photovoltaic solar energy becomes a significant renewable energy source in the near future”. The underlying assumption is that the market for PV systems is gradually expanding from the present niche markets of remote applications and consumer products, to the rapidly growing markets for building-integrated and other diffused and centralized PV power systems.

The primary scope of the programme has been the information exchange about activities already in progress in the respective national programmes. However a significant added value of the co-operation has been the informal co-ordination and initiation of new activities such as market surveys, the analysis of the operation and performance of a large number of PV systems already installed in the world, and the provision of the lessons learned as well as the guidelines for appropriate design improvements.

1.2 PVPS Task 2 work

Task 2 is an international collaborative programme focusing on operational performance, long-term reliability and sizing of PV systems and subsystems, providing technical information to PV experts, research laboratories, PV industry, utilities, system designers, installers, standardisation organizations and energy agencies.

Task 2 officially started its work on 16 April 1999 for a period of five years.

The member countries participating in Task 2 are Austria (AUT), France (FRA), Germany (DEU), Italy (ITA), Japan (JPN), The Netherlands (NLD), and Switzerland (CHE).

The overall objective of Task 2 is to improve the operation and sizing of photovoltaic power systems and subsystems by collecting, analyzing and disseminating information on their technical performance and reliability, providing a basis for their assessment, and developing practical recommendations for sizing purposes. Task 2 is a technical Task with a horizontal role to deliver services to the other Tasks within the PVPS programme. Maintenance of PV systems and subsystems is an important aspect of long-term plant operation and is included in the Task activities.

Task 2 activities are organized into the following Subtasks:

SUBTASK 1: International Database

Participants collect information on the technical performance, reliability and costs of PV power systems and subsystems by means of published and unpublished written materials, available monitoring data from national programmes and personal contacts. The information is then entered into a database providing technical data on operational performance, long-term reliability and sizing of PV systems. To ensure consistency, a data collection format and a set of standard definitions have been developed and agreed to.

The PVPS Task 2 Performance Database and programme has been developed and will be upgraded regularly. The Performance Database containing data of 316 PV systems adapted to various applications and located worldwide allows the user to select PV system data, present monitoring data and calculated results as well as to export these data into spread sheet programmes. A collection of such a variety of high quality operational data presents a unique tool for PV system performance analysis. The Performance Database (45 MB) is available on CD-ROM and can be downloaded from the website http://www.Task2.org.

SUBTASK 2: Evaluation of PV Systems

Task 2 experts analyze performance and maintenance data for photovoltaic power systems and components, both in order to ensure the quality and comparability of information gathered in the Performance Database and to develop analytical reports on key issues such as operational performance, reliability and sizing of PV systems. Activities to date include conference presentations and published reports on “Statistical and Analytical Evaluation of PV Operational Data”, “Analysis of the Operational Performance of the IEA Database PV Systems” and “Analysis of PV Systems”. Published in April 2000, the latest report illustrates the operational behaviour of 260 PV systems and presents detailed results in standard quantities allowing cross-comparison between the systems.

SUBTASK 4: Improving PV System Performance

In this activity, participants make recommendations on sizing of PV power systems and suggest improvements for better PV system performance. Participants identify tools to process and analyze data for performance prediction and sizing purposes. Applied energy management schemes are analyzed from the energy and operating cost points of view. Participants take account of the work performed in other Subtasks and work in collaboration with Tasks 3 and 7.

PVPS Task 2 work has been carried out to gather experiences and results of both technical and economical performance, for the promotion of PV. It aims at gaining an increased understanding of the operational performance, energy behaviour, characterization and design of photovoltaic systems, subsystems and components. In addition, performance analysis is a crucial element in the learning cycle of design - installation - monitoring - evaluation - and the improvement of the system design.

2 PERFORMANCE DATABASE PVPS TASK 2

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Overview

The IEA–PVPS Task 2 Performance Database is designed to provide PV experts and other target groups as well as other Tasks of PVPS with suitable information on the operational performance, reliability and costs of PV systems and components. The database application allows easy selection of PV system data and fast navigation through the database. Powerful tools enable the user to present monitoring data and calculated results in standard reports and to export these data into spread sheet programmes for later use.

At present the database contains high quality data of 316 monitored PV plants with an installed peak power of 10.8 MW adapted to various applications (power supply, domestic uses, rural electrification, professional applications). Detailed system characteristics of selected PV plants as well as monitored data are stored in the database. The new database features simplified data export to spread sheet programmes, improved filter and sort criteria to navigate in the database and an easy search for a specific PV plant. Data import and export facilities have been developed including automatic calculations of annual results. This tool can be used to check the operational behaviour of existing PV plants and to get a report on its performance results expressed in standard quantities allowing cross-comparison between the systems.

The implemented PV systems are located worldwide and operate therefore under different climatic conditions. Most of the monitoring data have been gathered under various national demonstration programmes in the IEA–PVPS member countries: e. g. Austrian Rooftop Programme, French Rural Electrification Programme, EU Thermie Programme, German 1000-Roofs-Photovoltaic-Programme, Italian Roof-Top-Programme, Japanese Sunshine & Field Test Programme and Swiss demonstration programmes. A collection of such a variety of high quality operational data presents a unique tool for PV system performance analysis.

The database application can be downloaded from http://www.task2.org/database/. Updates of the collected PV system data will be downloadable from this website as well.

Programme

The Performance Database contains information on 316 photovoltaic systems in IEA countries worldwide:

- General system information
  (size, system type, mounting, location, cost, photo)
- System configuration and component data
- Monitoring data
  (values of monthly energies, irradiation and temperature)
- Calculated data
  (monthly and annual values of performance indicators)

Data of grid-connected, stand-alone and hybrid photovoltaic systems of 1 kWp up to 3 MWp are available. Figure 1 shows the distribution of the monthly monitoring data in the database. New monitoring data and photovoltaic system data are continuously collected and will be entered into the database. Registered users can download updates from the Task 2 website *www.task2.org*.

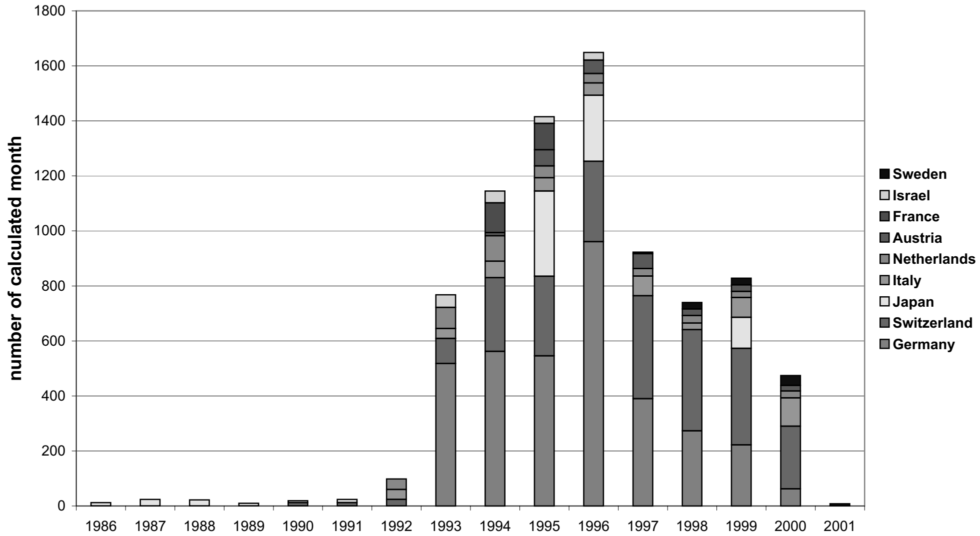


Figure 1: *Distribution of Monitoring Data*

The Performance Database consists of two main components: A database server and a user application programme. The application programme allows easy access to the data with modern elements like tree and list windows. Filter criteria and sort options enable easy navigation through the database and selecting specific photovoltaic systems.

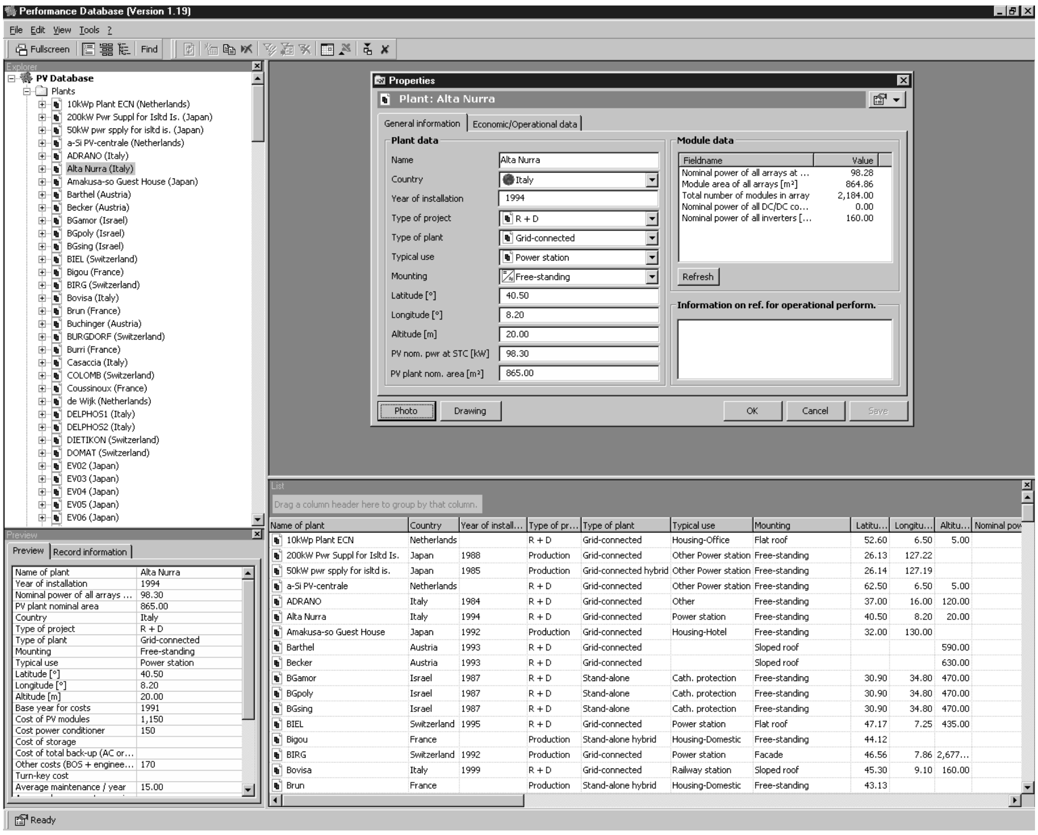


Figure 2: *Performance Database User Application*

The component structure of the photovoltaic system is visible in the Explorer tree (Figure 4), the main navigation element of the programme. A double click on an element will open a dialog window with further information. If a group item (for example: Plants or PV arrays) is selected, all elements will be shown in the list window. A simple mouse click on the column headline of the table is necessary to sort or group the elements in the list window.

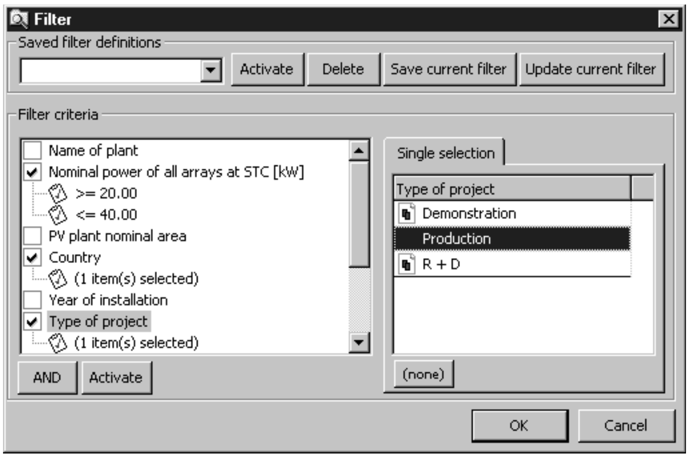


Figure 3: *Dialog for filter criteria*

Filter settings are useful to keep the visible data within manageable limits. The filter option allows a combination of different criteria. Also manual selections of photovoltaic systems are possible to reduce the visible systems in the explorer tree. This is important, because the export of data depends on the selected systems in the explorer tree. Monitoring data and calculated annual or monthly values are displayed in tabular form. Extensive export options are available to allow graphical presentations and further analysis:

- System and components overview
- Annual results for all selected plants in the explorer tree
- Monthly results for all selected plants in the explorer tree
- Report 1: prepared Excel sheet for one selected PV system
- Report 2: prepared Excel sheet for the comparison of maximum six PV systems

The spread sheet programme MS Excel is used for the data export.

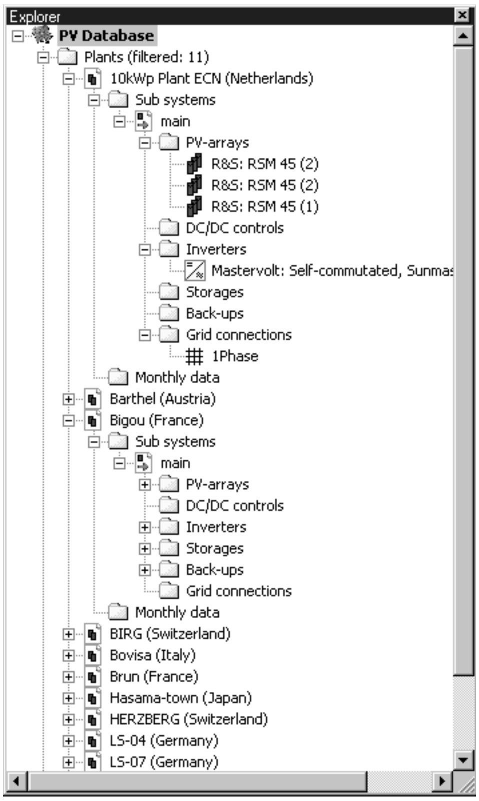
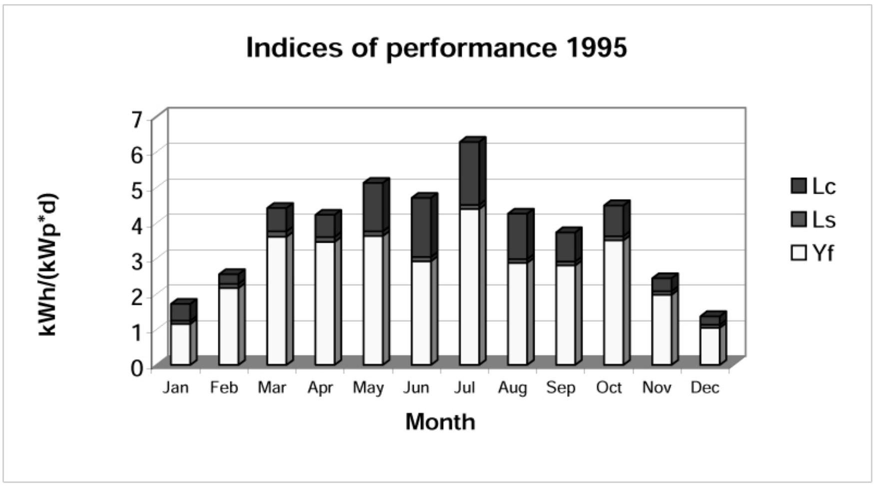


Figure 4: *Explorer window*

IEA PVPS Task 2 Photovoltaic Database Report

Plant Name	: **DOMAT**		
Country	: Switzerland		
Type of plant	: Grid-connected	Mounting	: Sound barrier
Nominal Power [kWp]	: 103.97	Array area [m²]	: 967.82



Year	1990	1991	1992		
Availability of monitored data	1.00	1.00	1.00	AMD	[ ]
Calculated month	12	12	12		
Meteorology					
Glob. Irradiation, horizontal	1253	1277	1243	H sum	[kWh/m²]
Irradiation, in array plane	1436	1422	1357	Hi sum	[kWh/m²]
Ambient air temperature	9.7	9.1	9.6	Tam avr	[°C]
System Energies					
Energy output from inverter	84151	114785	107697	EIO sum	[kWh]
Useful energy	84151	114785	107697	Euse sum	[kWh]
PV array fraction	1.00	1.00	1.00	FA	[ ]
Energy consumption				Econ sum	[kWh]
System performance Indices					
Reference yield	3.93	3.90	3.71	Yr avr	[h/d]
Final yield	2.22	3.02	2.83	Yf avr	[h/d]
Array capture losses	1.48	0.73	0.75	Lc avr	[h/d]
System losses	0.24	0.14	0.13	Ls avr	[h/d]
Performance Ratio	0.56	0.78	0.76	PR	[ ]
Array efficiency	6.7	8.7	8.6	eta A	[%]
Inverter efficiency	90.4	95.6	95.7	eta inv	[%]
Overall plant efficiency	6.1	8.3	8.2	eta tot	[%]
Utility Grid					
Energy to utility grid	84151	114785	107697	ETU sum	[kWh]
Energy from utility grid				EFU sum	[kWh]

Figure 5: *Example for the available export page for selected PV system*

The hard- and software requirements as well as contact information are given in annex D.

3 OPERATIONAL PERFORMANCE KNOW-HOW AND RESULTS OF PV SYSTEMS ANALYSIS

3.1 LARGE PV SYSTEMS IN ITALY

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Abstract: Today, 13 medium and large size PV plants ranging from 80 kWp to 3.3 MWp, with a total installed capacity of about 6.8 MWp, are operating in Italy. Although these systems have been monitored since their starting up, only for some of them operational data sets and maintenance information are available.

In the following, the operational performance of the most significant of them will be shown. In particular, the first grid-connected plant installed in Italy (Vulcano_1), the two sections of Delphos experimental plant and an example of medium size plant installed on building structures (Casaccia) will be analyzed. Moreover, in the field of MW plants the operational performance of Serre power station and of the multi-segment Vasto plant will be shown.

INTRODUCTION

Italian activities on medium and large size PV systems started in the early eighties with the aim to identify and validate satisfactory solutions and to assess the reliability of components and systems. Today, 13 grid-connected centralized systems ranging from 80 kWp to 3.3 MWp, with a total installed

Plant	Power [kWp]	Latitude	Tilt/ azimuth	Owner/Operator	In operation since	Datasets analyzed
Vulcano_1	80	38.3°	35°/180°	ENEL (ERGA)	1985	1997
Delphos_1	300	41.3°	20°/180°	ENEA	1986	1987 – 1999
Casaccia	100	42°	7°/225°	ENEA	1991	1992 – 2000
Delphos_2	300	41.3°	30°/180°	ENEA	1992	1992 – 1998
Vasto	1 000	42°	30°/180°	Industrial Consortium	1993	1997 – 2000
Serre	3 000	40,5	20°/180°	ENEL (ERGA)	1995	1995 – 2000
Leonori	86	41.8°	5°/200°	Private	1995	-
Carloforte	600	39	30°/180°	Industrial Consortium	1995	-
Lamezia	600	38.5°	20°/180°	Municipality	1996	-
Alta Nurra	100	40.5°	30°/180°	ENEA	1997	1997
Mandatoriccio	216	38.6°	20°/180°	Municipality	1997	-
Serre tracking	330	40.5°	-	ENEL (ERGA)	1998	1999
Vulcano_2	100	38.3°	30°/180°	ENEL (ERGA)	1999	-
TOTAL	**6 812**					

Table 1: *Main Italian PV plants*

peak power of about 6.8 MWp, are in operation in Italy and constitute over 1/3 of the total PV power installed in Italy. Most systems are mounted freestanding, facing south, with a tilt angle ranging from 20° to 30°. They are all located in the south regions of the country (latitudes 38° - 42°) at a maximum distance from the sea of about 15 km and at an altitude ranging from 50 m to 350 m above the sea level. In Table 1 the main features of the PV plants are listed.

PERFORMANCE OF PLANTS

Vulcano plant

The first experimental plant (Vulcano_1) was set up by ENEL in 1984 with the aim to assess technological, economic and operating aspects and to study the high penetration of PV in small isolated grids. The potential market of this application is represented by 33 small Mediterranean islands where the typical load range from 0.3 to 4 MWp and the cost of the electric energy is about 0.3 EUR/kWh. The plant can operate both in grid-connected and in stand-alone mode supplying about 50 isolated houses in this configuration [1]. In the period 1985 - 2000, the plant has produced about 70 MWh/year (60 % in grid-connected mode). Variations in the yearly energy production were due to both maintenance activities and faults and to experimentation and measurement campaigns. During visual inspections visible signs of rust discolouration of cell front contact have been largely encountered (30 %). Other module degradation signs regards delamination (1.5 %), glass cracking (1.5 %) and cell discolouration (15 %). However, almost all of the modules presenting degradation signs do not show power losses. In fact, periodical measurements have demonstrated an effective degradation of the PV array less than 5 %. Moreover, two modules and a junction box have been damaged by lightning, while several by-pass diodes were interrupted because of terminal soldering disconnection. Concerning the inverters of the plant, initial resetting were required and slight failures occurred especially during the first months of operation. Altogether, after 16 years of operation, the plant is nice looking, properly working and can still provide information on performance and lifetime.

Delphos plant

The Delphos (Demonstrative Electrical Photovoltaic System) project was aimed at developing and testing innovative components and advanced system architecture and to gather experience in construction and operation on large scale PV plants. The project, promoted by ENEA, consists of two sections, about 300 kWp each, built at different stages on the basis of different system concepts and put in operation in August 1986 and in January 1992 respectively. During the investigated period (1992 - 1998) 260 total outage events and 140 partial outage events occurred. By analyzing the outage causes, it was found that the inverter unreliability was the main cause of the total outages with a rate of about 4.2 failures/year for the first section and of 18 failures/year for the second section. Concerning partial outage events, it resulted that the PV generator unreliability was the most frequent cause [2]. Its average rate depends strongly on the ageing and ranges from 15 failures/year in the case of the first section to 4 failure/year for the second section. The forced maintenance work has required about 190 man-hours/year in the investigated period. This value proves that in the case of an immediate maintenance action, a plant unavailability of about 5 % can be achieved. In practice, a plant unavailability ranging from 15 % to 30 % has been recorded due to the time spent for detecting and locating the failure, for diagnosis and for supplying in situ the components to be replaced. On the whole, an average annual production of about 450 MWh has been obtained by the two sections of Delphos plant.

Casaccia plant

Casaccia plant is one of the six standard 100 kWp PV plants promoted by ENEA in the framework of the PLUG (Photovoltaic Low-cost Utility Generator) project. This project was aimed at achieving the minimum cost of the kWh consistent with the available technology resorting to the use of preassembled and standardized components and to a modular system architecture.

Casaccia plant started to operate at the end of 1991. Energy production has been inferior than expected due to the non optimum orientation of the PV array that was mounted on the already existing shelters of ENEA Casaccia Center parking.

The operational data collected so far have confirmed a daily final yield of about 2.5 kWh/kWp and a performance ratio of about 0.65. In the period 1992 - 2000 about 40 outage events have been recorded, corresponding to an average plant unavailability of 14%.

During the years 1997 and 1998 lower values of index of performance have been obtained owing to array partial shutdown due to sub-array junction boxes serious failure.

Good performances (daily final yield = 2.8 kWh/kWp and performance ratio = 0.7) have been obtained during the year 1999, when the installation has been in service almost 100% of the time.

In the year 2000, an attempt to repair the a.c. switch-gear and its consequent replacement have caused a total shut down of the system during the summer months.

Serre plant

In order to validate the project criteria adopted and to assess the scale effect, ENEL has developed a modular segment (330 kWp) to be used in large scale systems for utility applications. Serre power station is constituted of nine electrically independent modular segments, assembled on freestanding fixed structures with a 20° tilt angle and a tenth segment installed on a tracking structure rotating east-west on an horizontal axis. Being the tenth segment installed in 1998, only the performance of the first nine segments are analyzed.

The construction of the first nine segments of the Serre power station was completed in 1994 and operation commenced in early 1995. During this year, experimental data have shown a plant non-availability of about 27 % due to time spent in the first months of operation to adjust the inverters with respect to the frequent disturbances of the medium voltage local grid. As a consequence in 1995, low values of both performance ratio (0.47) and daily final yield (2.18 kWh/kWp) have been obtained [3]. In the period 1996 to 1999 the distribution of plant non-availability has ranged from 2.5 % to 5.3 %, because of some inverters outages due to filtering system, thyristors and input capacitors failures. In this period, the plant has shown good values of both performance ratio (0.66 - 0.68) and daily final yields (3.1 kWh/kWp - 3.3 kWh/kWp). Moreover, in this period the PV arrays have confirmed to be the most reliable components.

During the last years, inverter failures have strongly decreased and in the year 2000 no system outages occurred. For this reason the annual design values of the performance ratio (0.75) and daily final yield (3.6 kWh/kWp) have been closely confirmed by the experimental values obtained in the year 2000.

Vasto plant

Vasto plant (1 MWp) was the first large PV plant commissioned by ANIT with the aim to acquire experience on design and construction of large scale plant and to verify the higher plant reliability related to its inherent redundancy. The plant is constituted of two modular segments of 500 kWp each. This size has been selected taking into account applications like isolated networks, grid support and power stations. The plant was erected in 1994 and during the first operational year important maintenance activity on the power conditioning unit were required in order to detect the cause (resonance phenomena) of frequent thyristors, fuses and overvoltage protection failures. In the following years, maintenance interventions occurred in order to replace the medium voltage switch gear and the transformer, damaged by lightning. Other damages to cables and electronic cards were due to rats, while minor maintenance intervention occurred to detect ground faults. During the last four years, an average annual production over 1050 MWh has been registered. In the year 2000, no system outages occurred and good annual values of performance ratio (0.71) and daily final yield (3.2 kWh/kWp) have been obtained.

RESULTS

Although all the main Italian PV plants have been monitored since their starting up, only for seven of them (Vulcano_1, Delphos _1 & 2, Casaccia, Vasto, Serre and Alta Nurra) operational datasets with a total of 41 years of operation are available in the period 1987 - 2000. In Figure 1 the average values of the annual yields (Yf), system losses (Ls) and array capture losses (Lc) are shown, while in

Figure 2 the average annual values of the performance ratio (PR) and availability of the mentioned plants are reported. The daily final yield ranges from 2 kWh/kWp to 3 kWh/kWp, the daily array capture losses from 1.2 kWh/kWp to 2 kWh/kWp, the daily system losses from 0.2 kWh/kWp to 0.5 kWh/kWp, the performance ratio from 0.44 to 0.65 and the availability from 60% to 100%.

A more detailed analysis of the 41 operational years shows a large variation of the annual final yield ranging from 450 kWh/kWp to 1250 kWh/kWp (with a mean value of 864 kWh/kWp) and of the

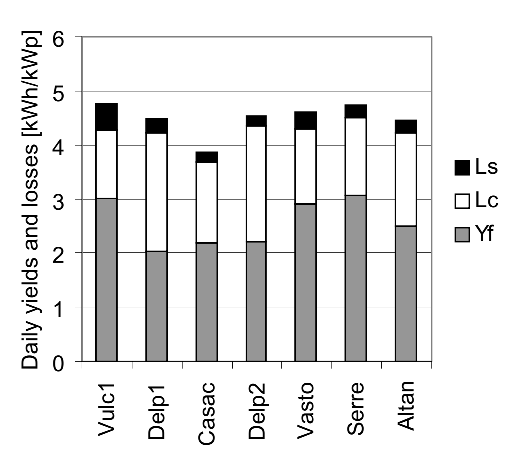

Fig. 1 - Final yields and losses

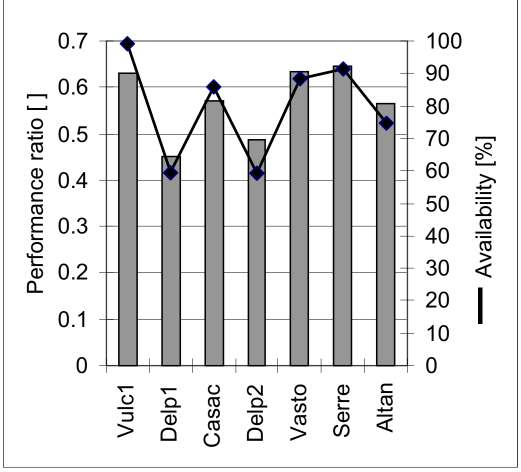

Fig. 2 - Performance ratio and availability

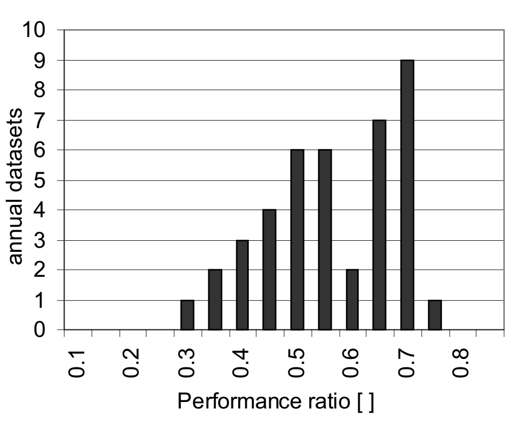

Fig. 3 - Histogram of Performance ratio

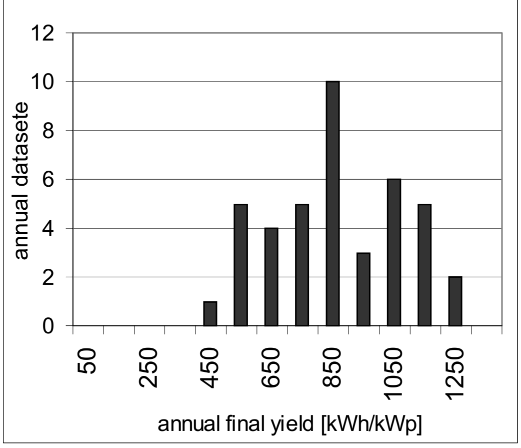

Fig. 4 - Histogram of annual final yield

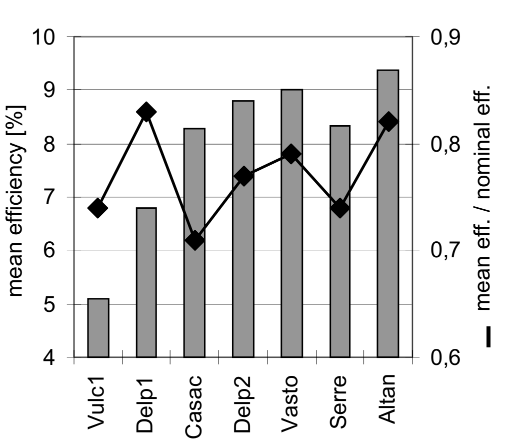

Fig. 5 - Mean array efficiency

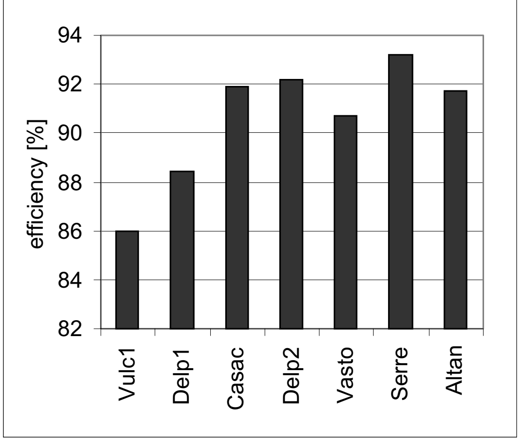

Fig. 6 - Mean operational efficiency of inverters

performance ratio ranging from 0.3 to 0.75 (with a mean value of 0.54) as illustrated in Figures 3 and 4. The large variation of the performance ratio is mainly due to the variation of the outage fraction (ranging from 0 to 0.6 with a mean value of 0.26) due to partial and total failures and a high non-availability of the plants. Moreover, the performance analysis of selected data has revealed that the mean value of the measured array efficiency ranges from 5 %, for the first prototypes installed in the eighties, to 9.3 %, for the PV plants constructed in the nineties, and that the ratio between the measured and the nominal array efficiency (according to the manufacturer's data sheets) ranges from 0.7 to 0.8 (Figure 5). Taking into account solar radiation losses (12 %), heating losses (2 % - 5 %), ohmic and mismatch losses (2 % - 3 %), a deviation (5 % - 10 %) of the measured power from the nominal power is confirmed, although module acceptance measurements have been performed before plant installation.

Concerning the efficiency of the inverters, the mean value of the annual operational inverter efficiency is ranging from 86 % to 93 % (Figure 6). Finally, from the economic data available, a decrease of the specific costs (not adjusted to the current year) of the plants from 20 EUR/Wp to 7 EUR/Wp has been observed during the past years.

CONCLUSION

The analyzed data have confirmed a continuous increase of plant performance during the past years. PV power stations such as Serre and Vasto plants have in fact shown good values of both performance ratio and final yield confirming their design values. Other plants (Delphos and Vulcano), more devoted to experimentation, have instead shown lower values of indices of performance mainly due to partial and total failure and a high plant non-availability due to experimental activities and measurements campaigns. However, these experimental plants, although not well performing from the production point of view, have provided and can still deliver information on performance and lifetime of components and subsystems and are useful to acquire experience on plant operation and maintenance procedures.

3.2 RESULTS AND FUTURE PLANS FOR MONITORING RESIDENTIAL PV SYSTEMS IN JAPAN

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Abstract: Outline of the two different Japanese governmental programmes for monitoring PV systems performances are presented. Some of the typical results of the performance analysis in these programmes are given. The future plans for the next phase monitoring programmes are also explained.

INTRODUCTION

Aiming at the national target of 5 GWp cumulative PV installation by 2010, the Japanese government launched several policies to promote introduction of PV systems nation wide in these years. Among these policies, two major subsidizing programmes, the field test programme and the residential PV monitoring programme have been very effective in promoting PV systems. The outline of these monitoring programmes and some results of the performance analysis are presented in this paper.

MONITORING PROGRAMMES IN JAPAN

Field test programme

The field test programme, initiated in 1992, is a cooperative research programme to accumulate operational data for PV systems in public and industrial sectors managed by the New Energy and Industrial Technology Development Organization (NEDO). About 1/2 to 2/3 of the installation costs are subsidized in this programme. The number of installations in each year is shown in Table 1. This is an on-going programme, and the target systems are public facilities for 1992 to 1996 and industrial appli-

Year	No. of sites	Total capacity [kWp]
1992	11	235
1993	19	476
1994	11	370
1995	31	719
1996	42	1 270
1997	70	1 830
1998	73	1 940
1999	97	2 920
2000	151	3 710
Total	507	13 470

Table 1: *Statistics of the field test programme*

Figure 1*: Example of field test programme*
20 kWp GCS for gymnasium (Ichinoseki city)

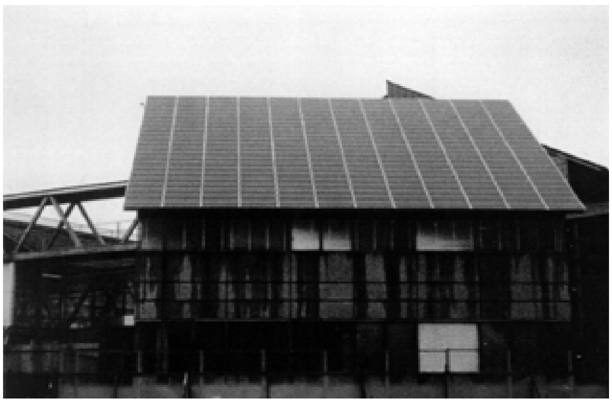

Figure 2*: Example of field test programme*
15 kWp GCS for university (Siga prefecture)

cations for 1997 and after. The capacity of the systems is ranging from 10 to 200 kWp. Some examples of the PV systems installed in this programme are shown in Figures 1 and 2.

The operational data measured in 10 minutes interval are gathered and analyzed by the Japan Quality Assurance Organization (JQA). The monitoring is going to be conducted for four years after the construction.

Residential PV monitoring programme

The residential PV monitoring programme, initiated in 1994, is a much larger promotion programme which subsidizes significant amount of installation cost of residential PV systems funded by the government and managed by the New Energy Foundation (NEF). The statistics of this programme is shown in Table 2. Over 58 000 systems with total capacity of 216 MWp are already installed in this programme, and the rapid increase in PV module production in Japan in these few years obviously is the result of this epoch-making programme. Unfortunately, this promotion programme is going to be terminated by FY 2002.

Year	No. of sites	Total capacity [MWp]
1994	539	1.9
1995	1 065	3.9
1996	1 986	7.5
1997	5 654	19.5
1998	6 352	24.1
1999	17 277	63.8
2000	25 741	95.8
Total	58 614	216.5

***Table 2**: Statistics of the residential PV monitoring programme*

Although the name of the programme contains the word "monitoring", this programme itself does not include any performance data monitoring scheme. To make use of this valuable source of performance data of residential PV systems, a detailed performance monitoring programme started in 1997 by JQA with the fund of NEDO [1]. Performance data are measured with one minute interval gathered and transmitted to the central host station via ISDN telephone line. 100 residential systems in total are on-line by the end of FY 2000. All 47 prefectures in Japan are covered by this programme.

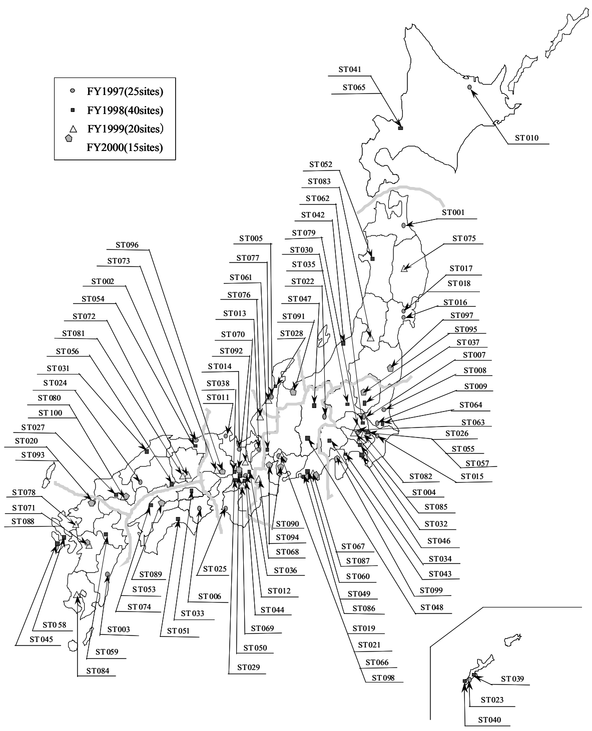

***Figure 3**: Location map of 100 residential PV monitoring sites*

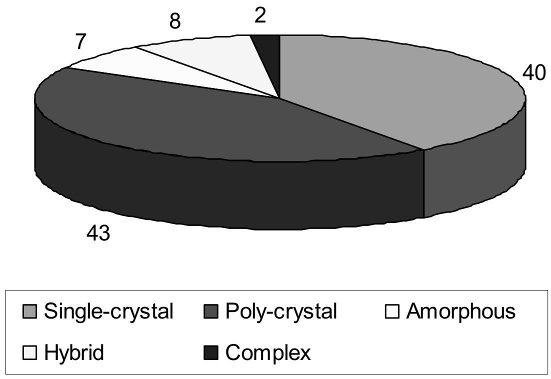

***Figure 4**: Types of PV modules in 100 residential PV monitoring sites*

***Figure 5**: Example of residential PV monitoring programme, 2.9 kWp GCS (Hanyu city)*

***Figure 6**: Example of residential PV monitoring programme, 3.5 kWp GCS (Hachinohe city)*

Figure 3 illustrates the locations of these 100 sites. Figure 4 is the breakdown of types of PV modules in monitored 100 systems. Some examples of these monitored systems are shown in Figures 5 and 6.

RESULTS OF PERFORMANCE ANALYSIS

Multiple year performances of PV systems of the field test programme [2]

The monitoring is done for four years in the field test programme. Multiple year performances of PV systems are analyzed using the monitoring data obtained in the field test programme during 1995 through 2000. Out of the 11, 33 and 42 systems installed in 1994, 1995 and 1996, 7, 16 and 25 systems are selected which have more than nine months data available, respectively.

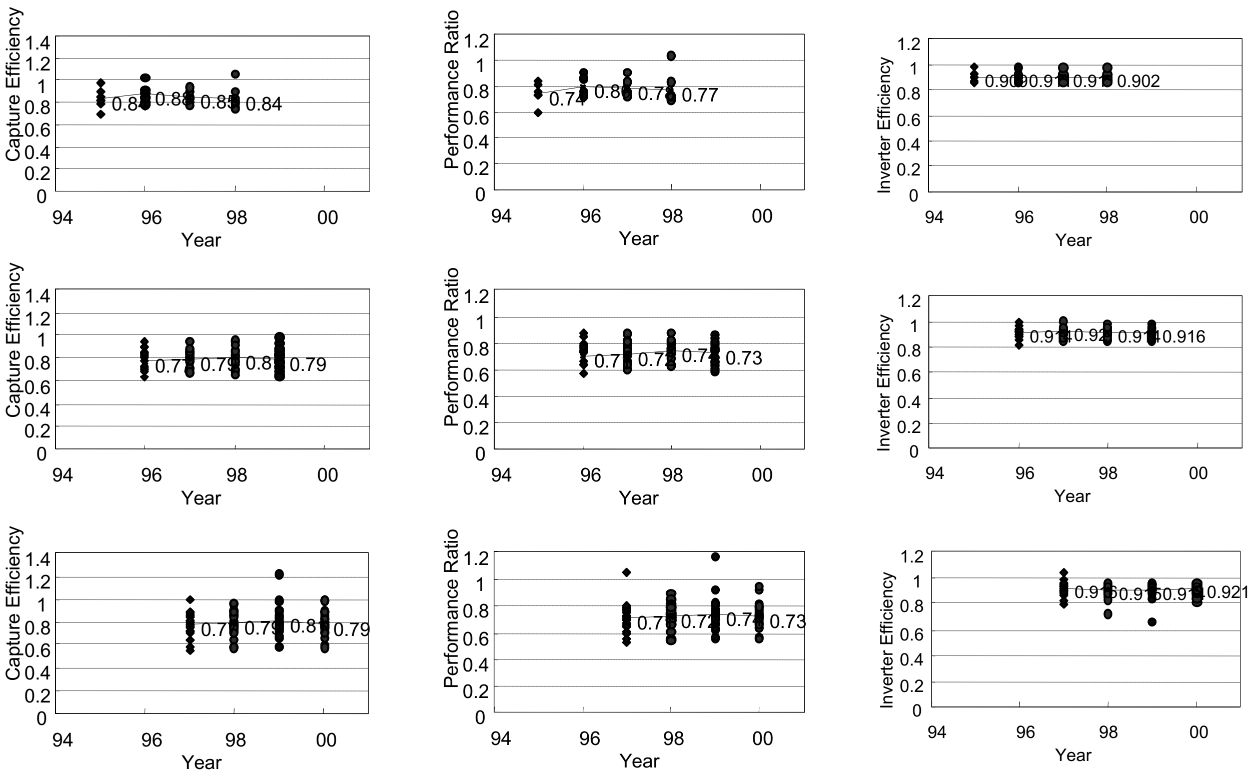

***Figure 7**: Changes in annual values of array capture efficiencies, performance ratios and inverter efficiencies for systems installed in 1994 to 1996*

The changes in annual values of array capture efficiencies, performance ratios and inverter efficiencies for the four years monitoring period are illustrated in Figure 7 together with the average values. No significant changes are found in these performance indices for the four-year period.

Slightly smaller values are found in the array capture efficiencies and performance ratios in the systems installed in 1995 and 1996. One reason is the change in the policies of the module manufacturer's rating for their products. More severe ratings are adopted in recent years. The increase in the numbers of systems with design-oriented arrays and multiply oriented arrays may be the other reason. The performance of these arrays can be smaller than the conventional single oriented ones.

Performances of PV systems in residential PV monitoring programme [3]

At the end of FY 1999, 85 residential PV systems were being monitored in the residential PV monitoring programme. Annual performance indices of these systems in the year 2000 are analyzed.

The distribution of the annual reference yield is shown in Figure 8. The average annual value of all the 85 systems is 1 340 kWh/kWp, and the standard deviation is 140 kWh/kWp. The average value is about the same as the data obtained in the previous year (1999) for 65 monitored systems which is 1 380 kWh/kWp.

The distribution of the annual final yield is shown in Figure 9. The average value of annual final yield is 990 kWh/kWp but there is a large difference between the minimum of 490 kWh/kWp and the maximum of 1 230 kWh/kWp. The average value of the previous year (1999) for 65 systems is 1 010 kWh/kWp. Shadings and MPPT mismatch are considered to be the most common reasons for the small values for these indices.

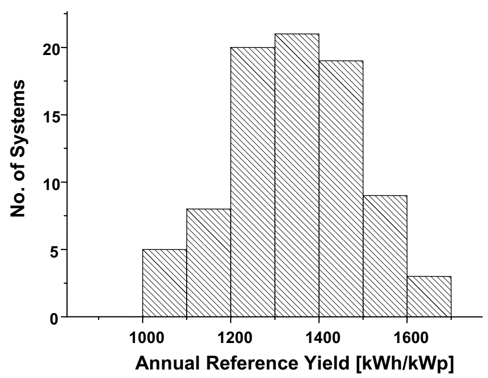

Figure 8*: Distribution of annual reference yield*

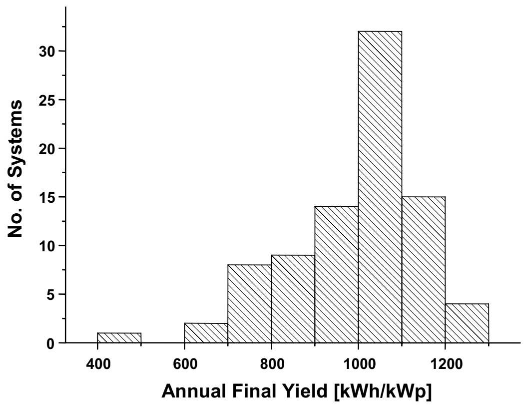

Figure 9*: Distribution of annual final yield*

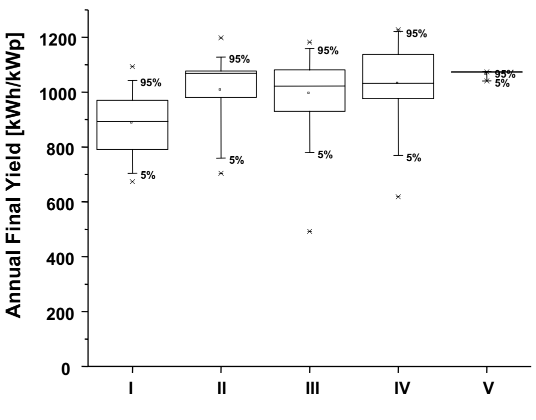

Figure 10*: Regional difference in annual final yield*

Figure 11*: Meteorological regions for irradiation in Japan*

The regional differences in the annual final yield are illustrated in the Figure 10. The abscissa represents the meteorological regions for irradiation in Japan classified by the Japan Weather Association, shown in Figure 11. It is observed that the annual final yield in region I, which is the northern part of Japan, where they have much snow in winter, is obviously smaller than in other regions.

Figure 12 shows the distribution of the performance ratio. The average value is 0.74, and again there is a large difference between the minimum of 0.43 and the maximum of 0.91. The average value of the previous year (1999) is 0.73, which is almost the same value.

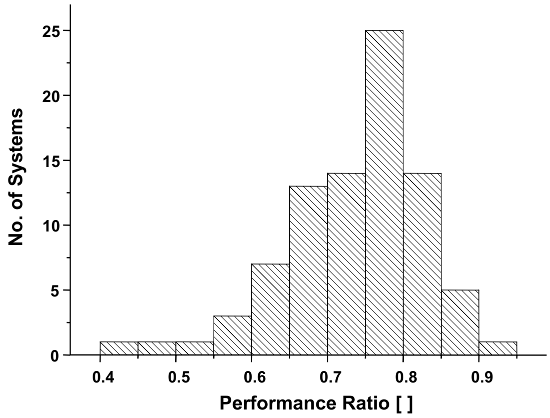

***Figure 12**: Distribution of performance ratio*

FUTURE PLANS FOR MONITORING PROGRAMME

The monitoring programme for 100 residential PV systems is taken over by the Japan Electrical Safety and Environment Technology Laboratories (JET) from FY 2001. Besides, a new monitoring programme for residential PV systems initiated in 2001 also by JET with the cooperation of the National Institute of Advanced Industrial Science and Technology (AIST). The aim of this new programme is to analyze new types of PV system including BIPVs, systems with multiple oriented arrays and systems with problems in grid-connection. The programme is planned for the period of 2001 to 2005. The total number of monitored systems are expected to be 20 to 30.

CONCLUSIONS

- The outline of the two different monitoring programmes in Japan, the field test programme and the residential PV monitoring programme, are explained.
- The results of the multiple year performance analysis in the field test programme are presented. No significant changes in performances identified for the four-year period are found for the systems installed from 1994 to 1996.
- The annual performance results of 85 residential systems in the year 2000 are analyzed in the residential PV monitoring programme. The average annual reference yield of 1 340 kWh/kWp, the average annual final yield of 990 kWh/kWp and the average performance ratio of 0.74 are obtained. A large dispersion is found in the final yield and performance ratio. The final yield of the systems in northern region is found to be somewhat smaller than of the systems in other regions.
- Future plans of the monitoring programme, which is aiming at more specific and detailed analysis of residential PV systems, are presented.

3.3 EXPERIENCES FROM LONG-TERM PV MONITORING IN SWITZERLAND

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Abstract: To date the Swiss contribution to the IEA–PVPS Performance Database comprises 51 grid-connected PV systems and a total of 2 650 monthly data sets. The PV plants and the monitored data analyzed are a representative sample of the 1 325 PV plants currently in operation in Switzerland. An overview of all the systems and some individual systems are presented in the paper.

PV in Switzerland

Since 1989 until the end of the year 2000 about 1 325 PV plants with a total of 12.7 MWp were connected to the national grid. This is 1.8 Wp/capita. The PV energy produced by these plants in this time period is estimated at 48 010 MWh.

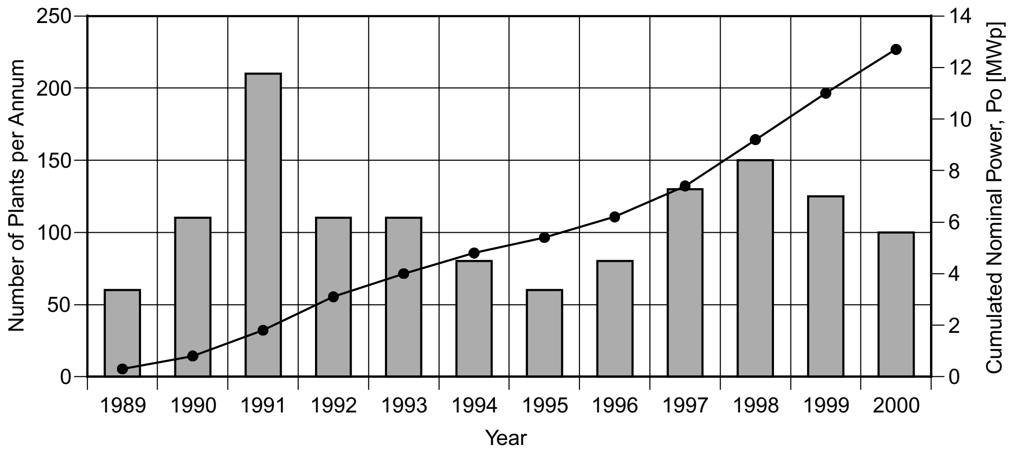
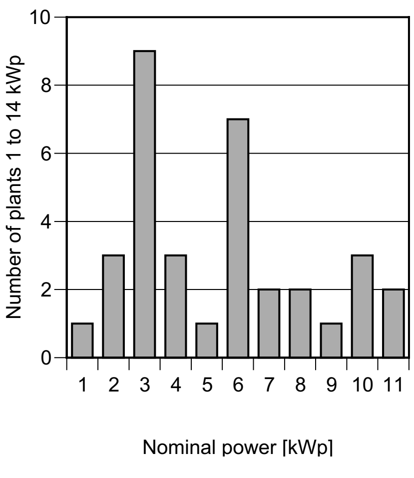


***Figure 1:** Number of PV plants annually connected to the national grid and cumulated nominal power of all the Swiss PV plants grid-connected by the end of the year 2000 (Source: Ch. Meier et al).*

The IEA–PVPS Task 2 Performance Database

The data of the Swiss 51 plants with a total nominal power of 1 576 kWp in the IEA–PVPS Task 2 Performance Database represent about 4.2 % in the number of plants or 14.3 % of the peak power of all the Swiss grid-connected PV systems built between 1989 and 1999.



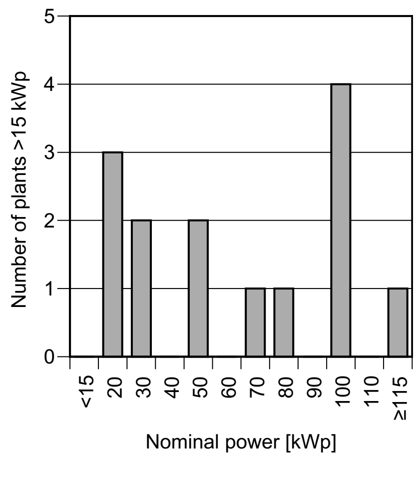


***Figure 2 and 3:** Nominal power of the Swiss PV plants in the IEA–PVPS Task 2 Performance Database.*

Monitored Data

The IEA–PVPS Task 2 Performance Database to date contains 51 Swiss grid-connected PV plants ranging from 1.3 to 560 kWp with monitored data from 1990 to 2000. The monitored data available for each plant covers one to eleven years plant monitoring or a total of 227 years of plant operation with a monitoring fraction of 0.95.

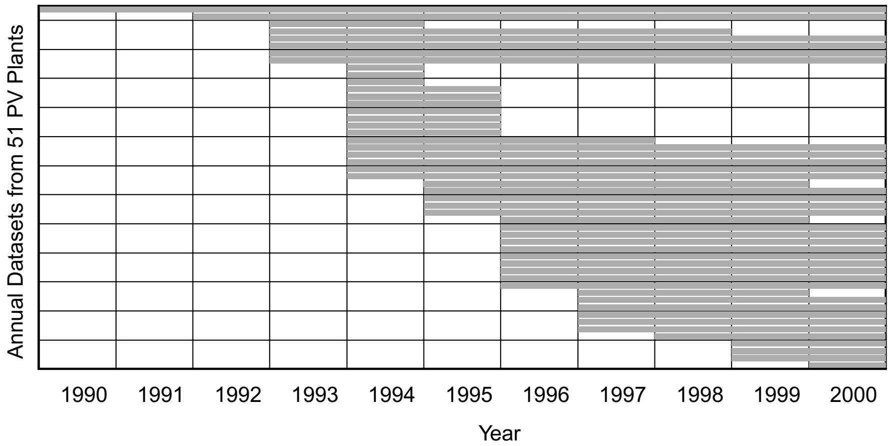


Figure 4: *Annual data sets of the 51 PV plants in the IEA–PVPS Task 2 Performance Database.*

In this monitoring period the 51 PV plants produced 8 340 MWh or 17 % of the total Swiss PV energy production for the same period.

A global view

Table 1, Figure 5 and Table 2 represent the nominal power, years of operation and the performance data calculated from the all the available data sets of the monitored plants. A 1 054 kWp grid-connected PV plant running for 10 years and producing a total of 8 340 MWh or 790 kWh/kWp per annum at a performance ratio of 0.68.

Name	Year of Installation	P_0 [kWp]	Years of operation
ALL PLANTS A	any	46.5	227
or			
ALL PLANTS B	any	1 054	10

Table 1: *Plant data of ALL PLANTS.*

The calculated results represent all the plants and all years of operational data in the IEA–PVPS Task 2 Database, including nine facade mounted plants and a few not so well performing systems.

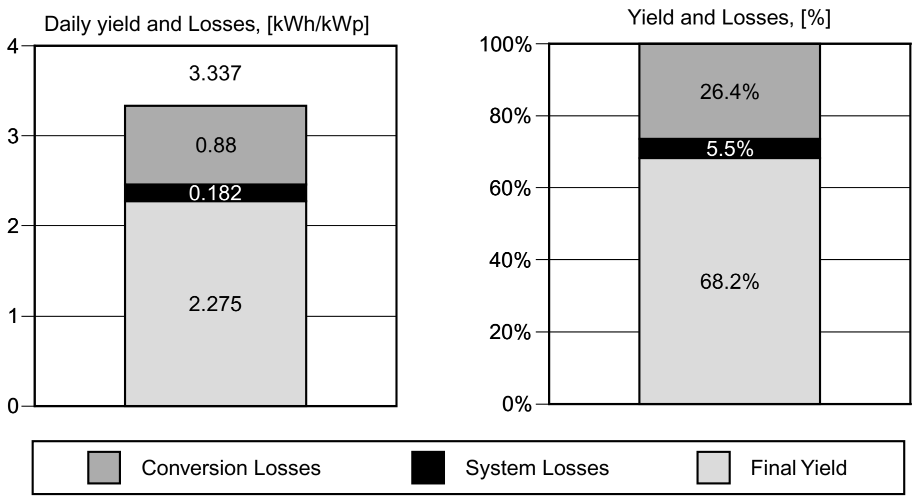


Figure 5 and 6: *Averaged yields and losses of all the total plants monitored.*

Name	Data	Annual H_I	$E_{TU\ total}$	O	PR	ηA_0	ηA	ηI	Annual Yield
	Years	[kWh/m^2]	[MWh]	[ ]	[ ]	[ ]	[ ]	[ ]	[kWh/kWp]
ALL PLANTS	10 or 227	1 160	8 340	0.05	0.68	0.119	0.087	0.93	790

Table 2: *Operational data of ALL PLANTS.*

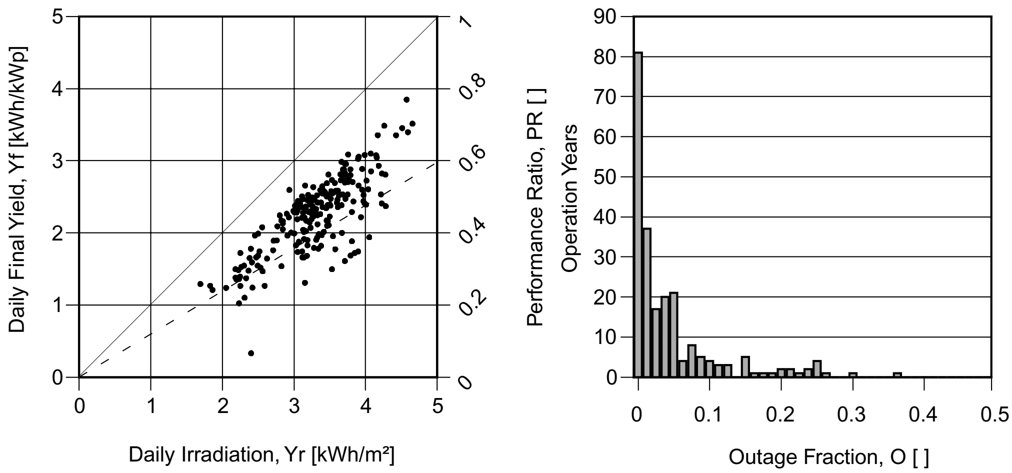


Figure 7 and 8: *Annual performance ratio and distribution of the annual outage fraction of all 51 Swiss plants with a total of 227 plant operation years.*

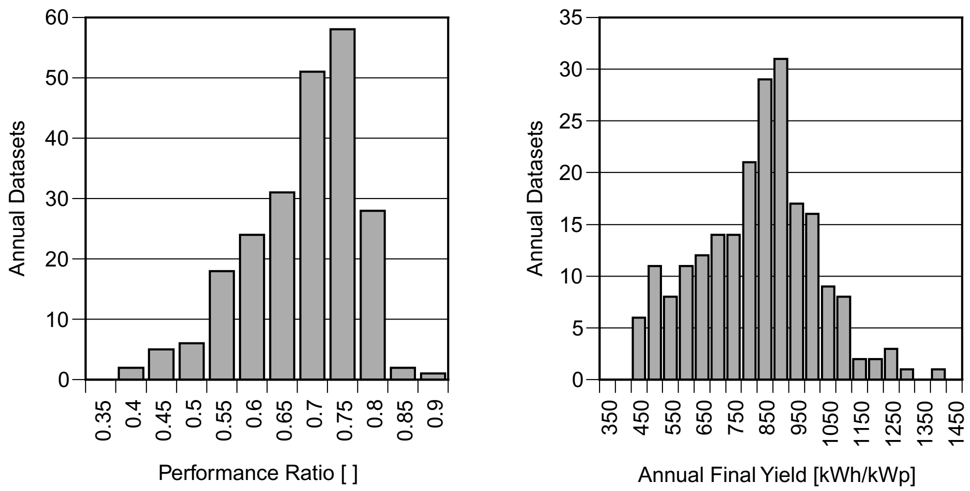


Figure 9 and 10: *Distributions of the annual performance ratio and the annual final yield of all the Swiss 51 plants with a total of 227 plant operation years.*

Some selected examples

For further investigation 10 plants were selected and the monitored data analyzed. The criteria for the selection was: years of operation - size - cell technology - mounting and some unusual behaviour due to: degradation of the cells or modules - shading and deposit of dirt on the surface of the module.

Name	Year of Installation	P_0 [kWp]	Mounting	Azimuth angle [°]	Tilt angle [°]
DOMAT	1989	103.9	Sound barrier	155	45
MAG	1992	103.0	Freestanding	195	45
MARZILI	1992	22.7	Rooftop	143	35
HERISAU	1993	6.36	Rooftop	160	45
USTER	1993	2.5	Facade	210	one-axis
SEVELEN	1994	2.97	Rooftop	180	45
GIEB	1995	104.30	Sound barrier	200	50
SCHAFF	1995	5.94	Rooftop	187	45
WETZIKON	1995	3.1	Rooftop	143	25
NEUCH	1996	3.8	Rooftop	180	one-axis

Table 3: *Plant data of the selected plants.*

Name	Data	Annual H_I	$E_{TU\ total}$	O	PR	ηA_0	ηA	ηI	Annual Yield
		[kWh/m^2]	[MWh]	[ ]	[ ]	[ ]	[ ]	[ ]	[kWh/kWp]
DOMAT	1990-2000	1 403	1 155.2	0.07	0.72	0.107	0.088	0.96	1 010
MAG	1993-2000	1 435	684.4	0.13	0.58	0.107	0.074	0.96	831
MARZILI	1993-2000	1 224	161.7	0.03	0.73	0.134	0.108	0.92	890
HERISAU	1994-2000	1 145	32.3	0.06	0.63	0.124	0.100	0.82	726
USTER	1994-2000	908	10.2	0.03	0.63	0.124	0.097	0.86	575
SEVEL	1994-1997	1 281	11.8	0.01	0.78	0.123	0.108	0.89	993
GIEB	1996-1999	1 112	380.9	0.01	0.82	0.139	0.123	0.97	905
SCHAFF	1996-2000	1 246	20.0	0.01	0.67	0.130	0.103	0.87	841
WETZI-KON	1996-2000	1 092	12.9	0.03	0.77	0.135	0.117	0.92	842
NEUCH	1996-2000	1 222	17.1	0.02	0.74	0.115	0.094	0.92	892

Table 4: *Measured data of the selected plants, sums and averages for the whole monitoring period. The values for ηA and ηI represent the measured efficiencies during the operation of the plant.*

The following figures [11 to 20] show the measured array efficiency of the selected plants. The array efficiency was recalculated to 25 °C cell temperature and all the data collected during non-operation of the plant was discarded. Any variation of the array efficiency represents shading, degradation of the cells, dirt deposits, partial disconnection, low irradiance or/and the position of the reference cell. Due to the geographical location and orientation of the array some plants show a lower array efficiency in the winter.

Figure 11: *The plant Domat performed exceptionally well for ten years. Initially some shading occurred until some plants were removed. The surface of the modules was never cleaned. In the 11th year of operation some failures in the inverter control circuits caused some interruptions. Some parts of the inverter control were replaced in October 2001.*

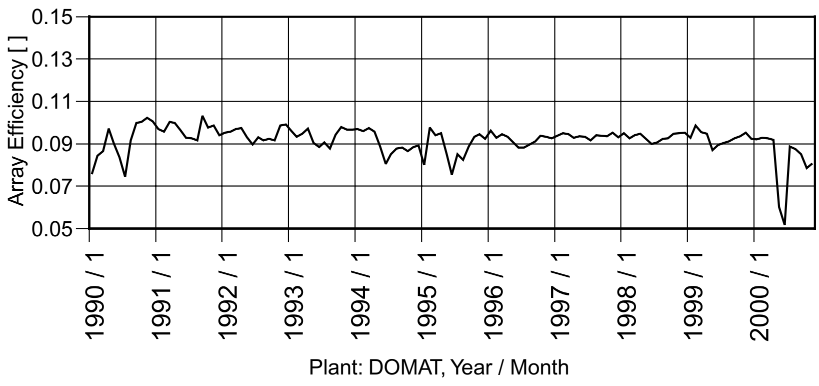


Figure 12: *In the first three years of operation the plant Magadino showed some degradation. In the summer of 1995 all the modules were cleaned. The dirt deposits came from a nearby waste incinerator plant, decommissioned in 1995. Further degradation was observed. Infrared scanning of the modules showed some "hot spots" due to a faulty internal electrical interconnection of some cells. Special I-V measurements on some selected strings showed some inconsistency. In 1998 the manufacturer agreed to replace all the modules. In 1999 some of the arrays have accidentally been disconnected. In the summer of 2001 the plant was completely overhauled and the inverter was replaced. Since October 2001 the plant is back on grid.*

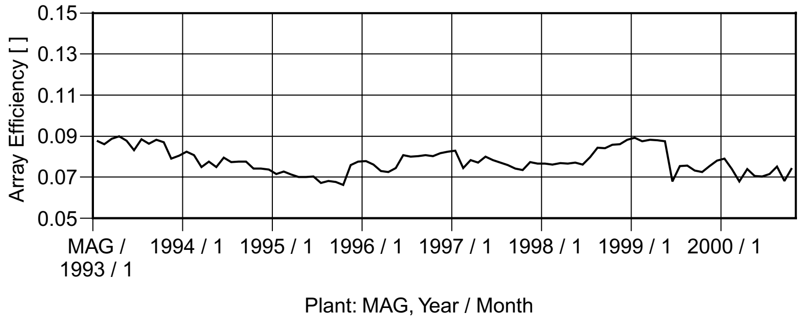


Figure 13: *The plant Marzili shows some initial degradation, but on the whole performed well. The surface of the modules was never cleaned. In 1999 some components of the monitoring system failed.*

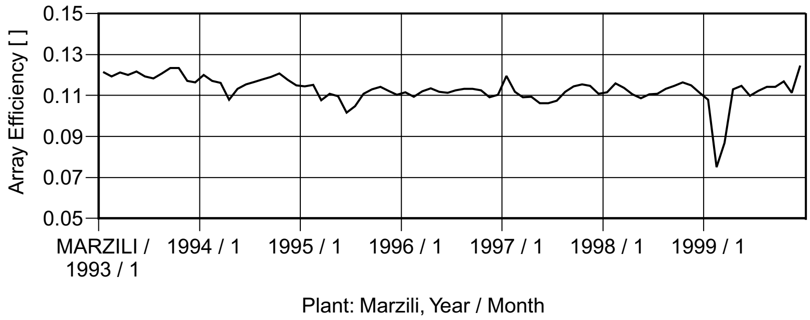


Figure 14: *Due to faulty wiring the plant Herisau did not deliver at full output from the beginning. In July 1999 there was a failure of one of the three inverters.*

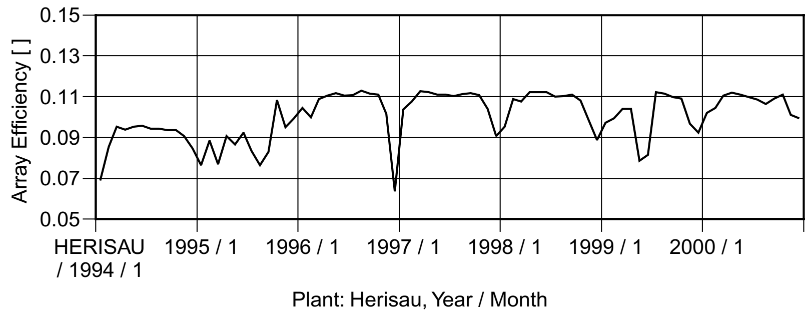


Figure 15: *This facade mounted plant Uster performed very well. One half of the array is tracked in the horizontal axis. The drop in the array efficiency in the late summer of 1995, 1996, 1998 and 2000 is due to the failure of one of the two inverters.*

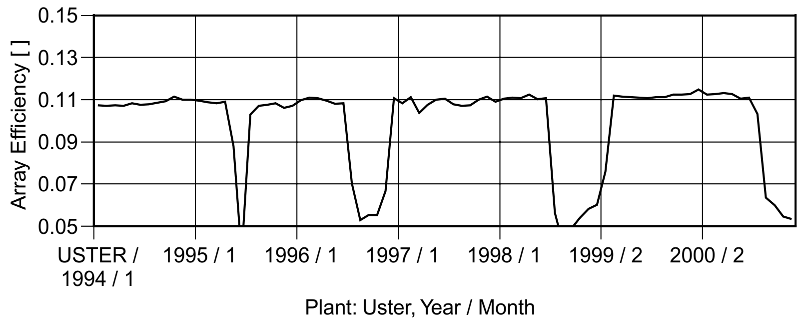


Figure 16: *This roof-mounted plant Sevelen shows perfect operation from the beginning of the operation.*

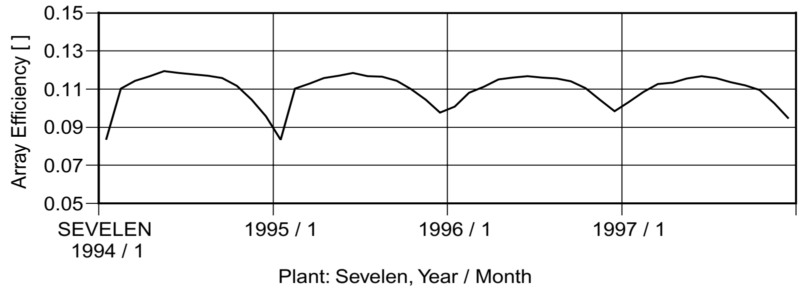


Figure 17: *This 100 kWp plant Giebenach mounted on a sound barrier along a motorway performed well most of the time. The drop in the array efficiency in late 1997 is due to shading from plants, which were subsequently trimmed.*

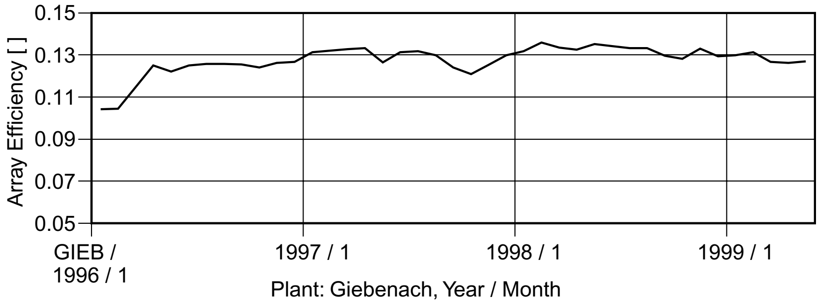


Figure 18: *The plant Schaffhausen performed well from the start.*

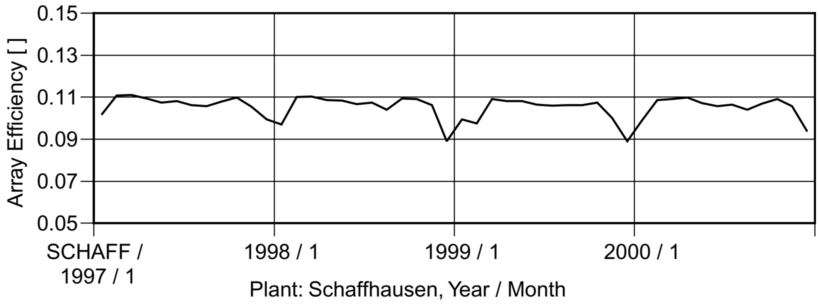


Figure 19: *The plant Wetzikon performed well. The drop in the array efficiency in the early winter is due to the orientation of the plant and possibly some shading.*

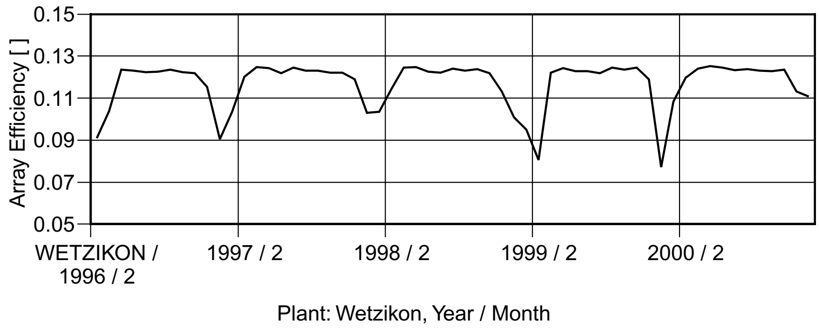
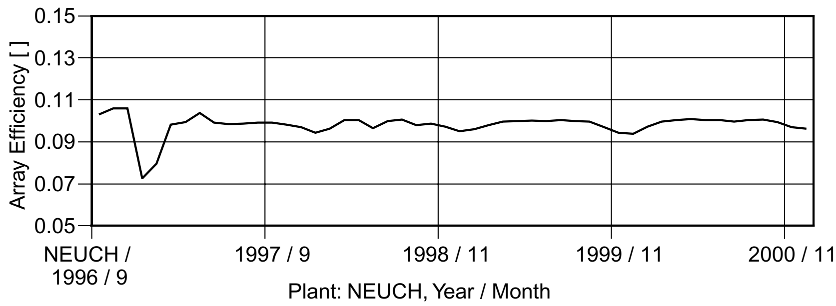


Figure 20: *Apart from some initial problems the tracking plant Neuchâtel performed well. It is interesting to note that the modules used for this plant are identical to the modules on the plant Magadino (Figure 12) but of more recent production.*



Conclusion

The IEA–PVPS Task 2 Database is a useful tool to analyze the behaviour of PV systems. In general the Swiss monitored data showed best consistency. It is however difficult to obtain information on the operation and maintenance of the individual plants from the owner/operator. It is also difficult to establish if a drop in the array efficiency is due to degradation of the cells or to dirt deposits on the surface of the modules. It is also not known if the reference device (reference cell or pyranometer) was ever cleaned or recalibrated. The analysis of the operational data as whole (ALL SYSTEMS) show a mean performance ratio of 0.68 and an annual final yield of 790 kWh/kWp. These values are lower than expected. This is partly due to the inclusion of nine facade-mounted systems. Newer systems tend to have lower failure rate (Ch. Meier et al) and as a result higher performance and yields.

3.4 RELIABILITY OF PV SYSTEMS IN AUSTRIA, LESSONS LEARNED

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Introduction

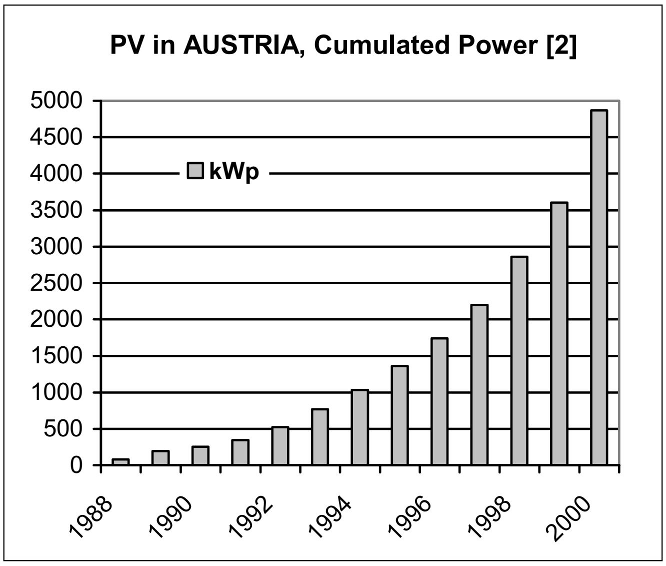
In Austria the renewable fraction of the primary energy consumption is 25 %. This is the highest figure of all EU member states. 70 % of the electricity used in Austria is produced by hydro power plants.

The new Austrian law to control the liberalized electricity market (ELWOG 2001) specifies that distribution utilities have to produce or purchase 4 % of their electricity demand using renewable sources like: biomass, landfill gas, PV, wind etc. The timeframe to reach this ambitious goal is 2007.

National Overview on PV in Austria

In the Austrian public, photovoltaic stands for innovation, ecology, renewable, energy efficiency, long-term thinking and smart technology. All this attributes attract a wide range of enthusiasts from different sectors of science, industry, utilities and trade. As in most countries in the world PV applications started with stand-alone systems to power small loads in remote areas without electric grid. More than a decade ago Austria's first grid-connected PV unit started operation in 1987 (1 kWp, Energie AG).

The mean system size of residential PV plants is about 3 kWp. The largest installation has a rated power of 200 kWp.



The market of grid-connected PV systems developed very well in recent years. The reason for this positive development can be seen in several very effective funding instruments:

- Vienna 3 636 €/kWp investment subsidy
- Upper Austria 3 636 €/kWp investment subsidy
- Carinthia 0.727 €/kWh PV tariff
- Styria 0.364 €/kWh PV tariff

Some funding institutions provided subsidies of up to 50 % of the total investment. Furthermore the electric utilities are engaged in pilot and demonstration plants.

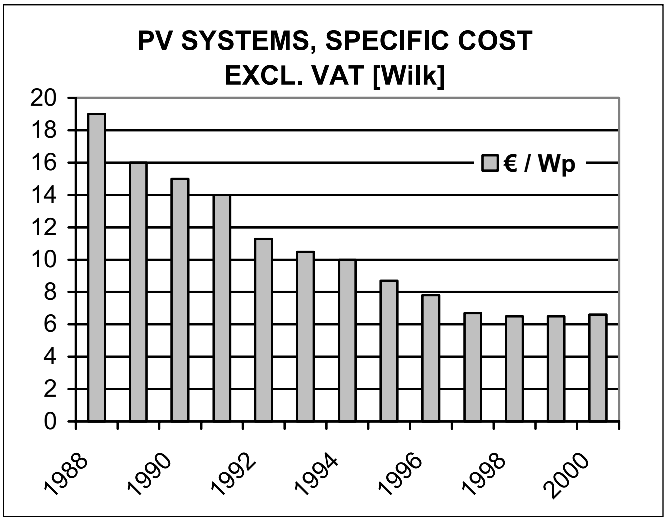
Today approximately 800 grid-connected systems are operated by private house owners (3 200 kWp by the end of 2000). Almost all of them are supported by one or another public funding programme. Between 1996 and 2000 the annual market growth was 25 %.

Penetration of grid-connected PV in Upper Austria reached 1 Wp/capita compared to the Austrian average of 0.5 Wp/capita.

Total system cost could be reduced to less than 50 % within the last decade. This was achieved because training of the installers and craftsmen was very efficient. Furthermore an increasing number of PV market players started competition on each PV project. In the last years module costs dropped only slightly because of the high demand in the German rooftop programme.

Reliability and Lessons Learned

To learn more about the performance and problems we started an investigation on PV installations in our service area. In our grid network in Upper Austria we supply electricity to 410 000 customers. Today 241 of them operate a grid-connected PV system (as of September 2001).



We distributed a questionnaire to all operators/owners of PV units. 52 % returned the data sheets within one month. In total we received data and information of 4 267 months of system operation.

We learned that about 50 % of the PV system operators are between 35 and 50 years of age. 90.5 % of the PV enthusiasts are male.

The main motivation to buy a PV system was to improve the environment (79.8 %) and a high interest in the technology of solar cell technology (72.6 %). The average size of a residential PV system was calculated to be 2.7 kWp (this figure excludes a big system of 75 kWp).

Our main interest was to learn more about the reliability of the power conditioning system (inverter unit). The inverter is a quite new electronic device still produced in relative small numbers. 60 % of the PV owners decided to buy an Austrian inverter (FRONIUS). 62 % of the systems are equipped with Japanese solar modules (KYOCERA).

37 % of the PV systems developed some problems. Only one outage was caused by blown fuse in the d.c. main line between array and inverter input. The dimension of this fuse was too small compared to the peak power of the array (design fault). All other system problems originated in the poor performance of the inverter or in interface problems with the utility grid. Nine system failures were caused by indirect lightning strokes that hit nearby grid distribution lines. In one case the grid voltage was too low for some periods of the day. The inverter switched off and no solar electricity was fed into the grid for some hours. This was very annoying to the PV system owner. In 14 PV systems the inverter power stage (bridge) developed a short circuit. As a consequence the design had to be modified. The d.c. choke coil of one inverter burned down because of an isolation failure. Five inverters needed new software because their controller lost memory after the operator tried to input a new set of parameters. Seven inverters showed a failure of a specific electronic component. A redesign helped to overcome this problem.

Waiting for repair: The mean outage time was about one week.

Summary

The summary of the survey is that one system failure occurred approximately every eight years. If we correct the numbers for already improved inverter design and the component updates we can expect a failure rate of one in every 15 years of operation. We also have to expect one inverter damage caused by lightning stroke every 39.5 years. We also learned that the failure rate of PV modules is very low.

We are optimistic that the PV market will steadily continue to grow in Austria at a rate of 25 to 30 % per year. About 50 % of the increase of grid-connected systems can be found in Upper Austria. Vienna and Carinthia follow with effective funding institutions.

Our survey showed that on average 850 kWh are produced per one kWp installed every year. With new installations annual yields could be increased to more than 900 kWh/kWp. The overall system performance can be further improved by optimizing several factors. Better inverters (e.g. without transformer) and modules with correct name plate rating will help to improve the yields of grid-connected PV systems in the future. As an average value, approximately 300 kWh were exported annually to the grid for every kWp installed.

[1] Austrian Member of ExCo - IEA–PVPS Implementing Agreement
[2] Market Data compiled by Prof. G. Faninger

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4 IRRADIATION IN THE BUILT ENVIRONMENT

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Abstract: In this paper a number of obvious and less obvious differences are discussed between the irradiation on ideally situated PV systems and on PV systems in the built environment. The relevance of these differences has been quantified by conducting a case study, using data from measurements and from simulation models. The main conclusions are:

- The loss due to non-optimal orientation and the loss due to shading can be simulated using existing tools. More measurement data are required for validating the shading models.
- The reflection loss and the low irradiance loss can be simulated using existing tools. Both loss items depend on the orientation of the modules.
- No easy-to-use simulation tool exists for the quantification of the spectral effect. The spectral effect can be significant for amorphous silicon.

INTRODUCTION

The irradiation available for a PV system plays a primary role in the annual yield of the system. Knowledge on the irradiation is required for economical feasibility studies and for optimization of the system layout. The available irradiation for PV systems in the built environment is much harder to predict than for ideally situated PV systems.

In this paper a number of obvious and less obvious differences between the irradiation on ideally situated systems and on building-integrated systems are discussed. The relevance of these differences has been quantified by conducting a case study, using data from measurements and from simulation models. The case study and its results are described below.

CASE STUDY

Four amorphous silicon PV systems on the façades of an office building of ECN have been used for the study (see Figure 1). The façades are vertical and face North (353°), East (83°), South (173°) and West (263°). Neighbouring buildings form obstacles towards the North, East and South while the West façade has a free view towards the West (see Figures 2a and 2b).

The following irradiation sensors were used:

- A horizontally mounted pyranometer on the roof
- A horizontally mounted pyranometer with shadow ring on the roof
- A vertically mounted pyranometer on each of the façades
- A vertically mounted reference cell on each of the façades.

***Figure 1:** The office building showing two of the four PV systems*

***Figure 2a:** View from the roof towards Southeast*

***Figure 2b:** View from the roof towards West*

The reference cells were made of crystalline silicon and a special filter, which has resulted in reference cells with the spectral characteristics of amorphous silicon modules.

ORIENTATION LOSS

The orientation of an ideally situated system is optimal (South, 35° tilt for the Netherlands) while building-integrated systems have orientations defined by the building. It is obvious that this causes differences in the available irradiation.

The irradiation has been calculated for the four façades and also for the optimal orientation in the Netherlands using the simulation tool PVSYST (with the model of Perez). The input for this calculation was the hourly data of the total irradiation on the roof and its diffuse component as measured with the pyranometers on the roof during a complete calendar year. The output of PVSYST was checked against the measured data of the (unshaded) West façade, obtained with the pyranometer. On annual basis the calculated irradiation on the West façade was only 2 % lower than the measured value which gives confidence in the simulations.

The values of the orientation loss alone, without the contribution of the other loss items, have been simulated with PVSYST for the four façades. The results, expressed in percents of the irradiation on the optimal orientation, are given in Table 1.

North	East	South	West
75 %	56 %	31 %	44 %

***Table 1:** Orientation losses expressed in percents of the irradiation on the optimal situation (South, 35° tilt)*

SHADING LOSS

The effect of shading includes the loss of direct irradiation from the sun, the loss of diffuse irradiation from the sky and the loss of diffuse ground-reflected irradiation. Most of the available simulation tools for shading follow the so-called “far shading approach”. In this approach the shading obstacles are projected against the horizon. Some of the simulation tools follow the “near shading approach”. In this approach the PV system and the shading obstacles are described 3-dimensionally which facilitates the calculation of shading for e.g. each individual module of the PV system.

One of the simulation tools that follow the near shading approach is PVCAD. However, this tool neglects the ground-reflected irradiation completely. PVSYST offers both approaches. Using the near shading approach of PVSYST, the irradiation has been calculated for the four façades. The input for this calculation was the hourly data of the total irradiation on the roof and its diffuse component as measured with the pyranometers on the roof during a complete calendar year. The differences between the simulated and measured annual irradiations on the four façades are between 4 % (East) and 8 % (South). These differences are larger than for the (unshaded) West façade. This is probably caused by the reflection of irradiation on the neighbouring buildings towards the PV systems. This augmentation of irradiation is not taken into account by PVSYST.

Because the shading in the test case is rather mild, a thorough validation of the shading models is not possible. For a proper validation measurement data of other test cases with more severe shading is required.

The shading effect has been calculated by running PVSYST with and without the neighbouring buildings. The ratio of the simulated irradiation values for the simulation with and without the neighbouring buildings are the shading effects (see Table 2).

North	East	South	West
1 %	6 %	7 %	0 %

Table 2: *Shading losses*

REFLECTION LOSS

Part of the irradiation is reflected on the front side of the PV modules. The reflection loss depends on the angle of incidence of the irradiation on the module surface. Since the orientation of the modules in the built environment differs from the ideally situated modules, also the reflection loss of building-integrated PV might be different from the reflection loss of ideally situated systems.

Measured information on the reflection loss can be obtained by comparison of the reading of a pyranometer and a reference cell, placed next to each other. The differences between these readings are caused by the differences in reflection on both instruments but also by the differences in the spectral responses of both instruments. Around noon of 11th September 2000, the spectral effect can be neglected since the spectrum was close to the standard spectrum (clear sky, AM 1.5). The reflection loss on the West façade however was very strong due to the grazing incidence of the irradiation around noon. The reading of the pyranometer and the ratio between the readings of the pyranometer and reference cell on that date are shown in Figure 3. The reflection loss as calculated by PVSYST (ASHRAE model with reflection parameter bo = 0.1) is also given in Figure 3. Comparison of the simulated and measured reflection losses shows that the model performs rather well. Hereafter the model has been used to calculate the annual reflection losses for the four façades (without the neighbouring buildings) and also for the optimal orientation (South, 35° tilt). The results are given in Table 3.

North	East	South	West
12 %	9 %	10 %	8 %

Table 3: *Reflection losses (for comparison: South, 35° tilt: 6 %)*

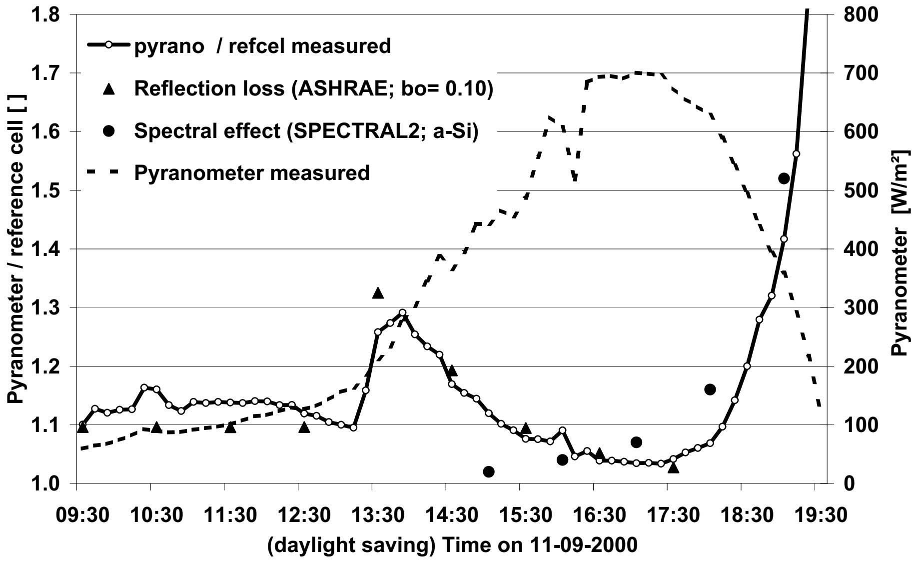

Figure 3: *Measured and simulated reflection loss and spectral effect on the West façade*

SPECTRAL EFFECT

The nominal power of a PV module is defined for a standard spectrum (AM1.5). Changes in the spectrum can cause positive or negative changes in the module output. Because the orientation of a building-integrated system differs from that of an ideally situated system also the “harvest time” differs. The harvest time of an ideally situated system (facing South) is around noon while the harvest time of e.g. a system on a West façade is in the afternoon. Differences in the harvest time correspond to differences in the spectrum and consequently to differences in the module output.

The spectral effect depends on the irradiation spectrum and on the spectral response of the applied PV modules. The spectrum can be calculated using the model SPECTRAL2 for clear sky situations. With this model the spectra has been calculated for the afternoon of 11th September 2000. The spectral response of the reference cells (designed to be identical to the spectral response of amorphous silicon) has been measured in the ECN laboratory. Combining these data resulted in simulated values of the spectral effect, given in Figure 3. Comparison with the measured data shows that the simulation with SPECTRAL2 performs rather well. Unfortunately this model is only valid for clear skies and cannot be used for an annual assessment of the spectral effect.

Since no simple-to-use model is available for the determination of the annual spectral effect, this effect has been quantified in an indirect way. The calculations have been performed for the façade with the strongest spectral effect (West). The ratio of the irradiation as measured with the pyranometer and the reference cell has been calculated from the measurement data. PVSYST has been used to calculate the reflection losses. The measured differences between the pyranometer and the reference cell data that could not be accounted for by the simulated reflection losses have been attributed to the spectral effect. The results are given in Table 4 and Figure 4.

Measured ratio	Reflection part	Spectral effect
1.13	1.08	1.05

Table 4: *Measured annual ratio between the readings of the pyranometer and the reference cell, simulated reflection effect and the remaining spectral effect (West façade, amorphous silicon modules)*

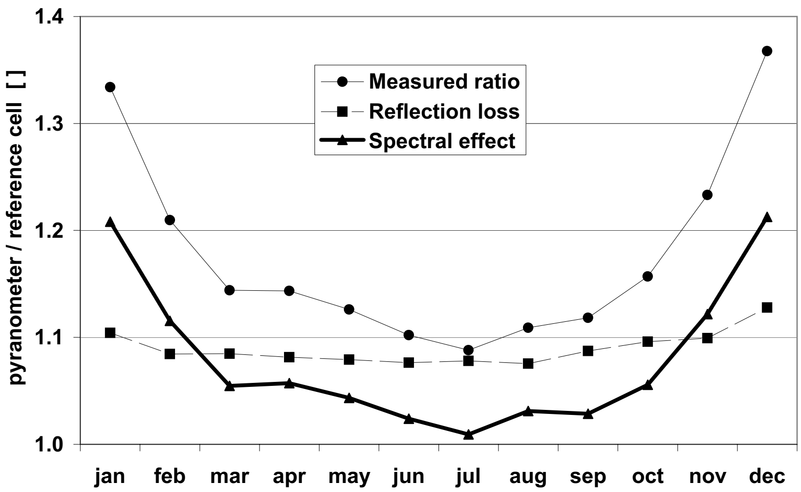

Figure 4: *Measured monthly ratio between the readings of the pyranometer and the reference cell, simulated reflection effect and the remaining spectral effect (West façade, amorphous silicon modules)*

LOW IRRADIANCE LOSS

The efficiency of PV modules at low irradiance values (low light intensities) is lower than at high irradiance values. This causes a loss in the output of a module compared with the ideal situation that the efficiency is not lower at the low irradiances.

This low irradiance loss depends on the efficiency curve of the module and of the frequency distribution of the irradiance. The latter depends on the orientation of the module. As an example the frequency distribution of the irradiance as measured over a complete calendar year on the South and on the North façade is given in Figure 4. Using the measured frequency distributions of the four façades and the measured efficiency curve of the amorphous silicon modules, the low irradiance losses have been calculated. The results are given in Table 5.

North	East	South	West
20 %	10 %	5 %	7 %

Table 5: *Low irradiance loss (for amorphous silicon)*

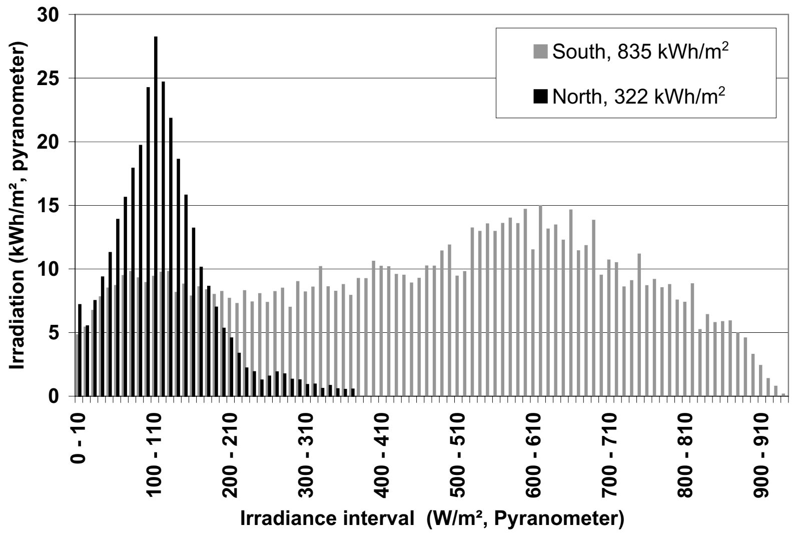

Figure 5: *Annual frequency distribution of the irradiance on the North and South façade*

CONCLUSIONS

- The loss due to non-optimal orientation and the loss due to shading can be simulated using existing tools. More measurement data are required for validating the shading models.
- The reflection loss and the low irradiance loss can be simulated using existing tools. Both loss items depend on the orientation of the modules.
- No easy-to-use simulation tool exists for the quantification of the spectral effect. The spectral effect can be significant for amorphous silicon. It is expected however that for other module technologies the effect is smaller.

ACKNOWLEDGEMENT

This work was supported by the Netherlands Agency for Energy and Environment NOVEM.

5 PERFORMANCE ASSESSMENT FOR PV STAND-ALONE SYSTEMS

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Abstract: The paper presents the first conclusions on the performance assessment of PV stand-alone systems from the analysis of nearly 30 stand-alone systems (SAS) installed worldwide with peak powers varying from 450 Wp to 1 500 Wp. The question to be answered is how to define a "quantity" able to deliver information on the performance of SAS not only in the energy but also in its technical behaviour point of view. It has highlighted that the Performance Ratio (PR), widely used for grid-connected systems, cannot be used alone to describe the operation of SAS. Some other factors have been introduced with the aim to complement the information accessible from on-site measurements: the Matching Factor (MF) and the Usage Factor (UF). These two factors are presented and have been applied on the 43 annual data sets available in the database. The first results allow to draw some preliminary conclusions, which will necessitate a validation step on the most possible available data.

5.1 Existing quantities for system performance assessment

These are the quantities usually used to assess the performance of PV SAS:

Array yield	$Y_A = E_A / P_0$	[kWh/kW$_p$]	P_0	: Peak power [W$_p$]
Reference yield	$Y_r = H_i / G_{STC}$	[kWh/kW$_p$]	H_i	: Mean irradiation in the plane of the array [kWh/m^2]
Final yield	$Y_f = E_{PV} / P_0$	[kWh/kW$_p$]		
$E_{in} = E_A + E_{BU}$	$E_{PV} = E_A \cdot E_L / E_{in}$		G_{STC}	: Reference irradiance at STC = 1 [kW/m^2]
Capture losses	$L_C = Y_r - Y_A$	[kWh/kW$_p$]	E_A	: Array output energy [kWh]
System losses	$L_S = Y_A - Y_f$	[kWh/kW$_p$]	E_L	: Energy to loads [kWh]
Performance ratio	$PR = Y_f / Y_r$	[ ]	E_{BU}	: Energy from back-up system [kWh]
Array efficiency	$\eta_A = E_A / H_i \cdot A_A$	[ ]		
Total efficiency	$\eta_{tot} = E_{use,PV} / H_i \cdot A_A$	[ ]		

The performance ratio (PR) was introduced to characterize the system operation whatever the application considered. It figures out how the potential energy of a PV systems is used. This potential energy is defined in Standard Tests Conditions (STC).

The higher PR is, the better the system uses its potential. A low PR value means production losses due to technical or design problems.

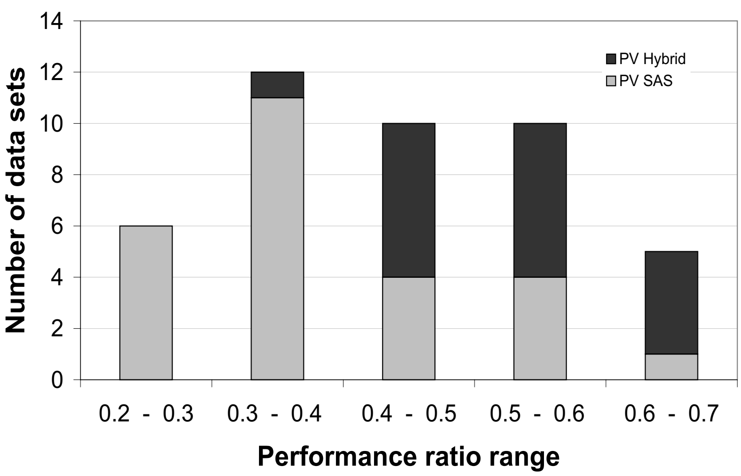

Figure 1: *Range of yearly performance ratio for typical domestic stand-alone systems*

In stand-alone systems, a high PR value does not always mean that the system is operating in the best conditions. If the system is under designed for the considered application, the PV system will show very high value of PR, but at the same time the user will not be supplied with electricity.

An oversized system will have to face frequent array (partial or total) disconnections affecting directly the PR value.

The analysis of the systems performance in terms of PR (Figure 1) shows that SAS present a wide range of PR which does not reflect the proper operation of a system in a technical point of view (component degradation, low efficiency components) as it is the case for grid-connected systems.

The value of the PR is user consumption dependent. If the consumption level is not correlated to the potential of the PV generator, the PR will reach values which can be less than 20 % at a monthly basis. Such a low value is due to high capture losses.

Hybrid systems characterized by the use of the back-up generator, as stated earlier, can show good performance if the consumption level matches quite well with the potentiality of the PV generator (Figure 2).

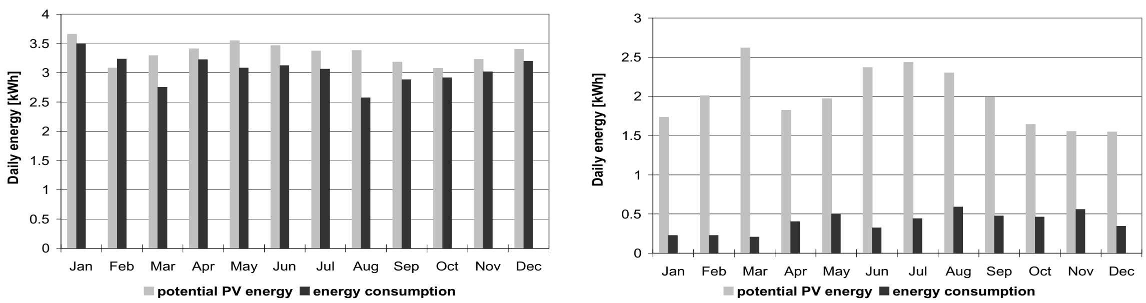

Figure 2: *Consumption level measured in two different systems (PR = 0.65 and PR = 0.20)*

The potential PV energy is what should be produced without any regulation process.

5.2 Matching Factor (MF)

The matching factor is calculated by multiplying the PR with the array fraction (FA). This array fraction equals 1 for PV SAS and decreases as the use of a back-up system increases.

The introduction of the Matching Factor (MF) allows a better illustration of the performance of hybrid systems. A high value of the MF indicates that the solar part properly matches the electrical load while limiting the back-up contribution.

Annual MF in the range 0.2 to 0.6 were achieved highlighting better performance of hybrid systems in general in comparison to PV SAS. Nevertheless the considered hybrid systems have not been designed as such, but as a juxtaposition of two sources (PV solar and conventional). The wide MF range demonstrates that an optimization in the design phase is always needed. The maximization of MF provides basis for more work regarding sizing rules of hybrid systems.

5.3 Usage Factor (UF)

A SAS which is not operating properly will show a low PR. But as it has been demonstrated this is not reciprocal. In order to have an idea on how the system is using the potential solar energy, a new factor has been introduced, defined as follows:

Usage Factor = Energy supplied by the generator / potential PV energy.

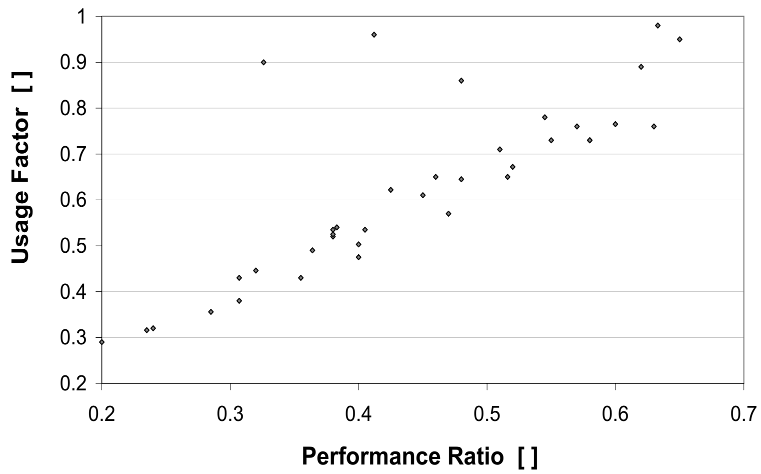

Figure 3: *Usage Factor as a function of Performance Ratio*

Figure 3 indicates that for most of the systems the Usage Factor is more or less a linear function of the PR. The better the system uses its solar potential, the higher the PR is.

However, there are three systems which are outside this linear tendency. When analyzing their operation characteristics, it can be seen that for these peculiar systems, the systems losses are abnormally high.

Indices of performance for two systems presenting the same PR value (PR=0.3) but very different UF (UF=0.45 and UF=0.9) are illustrated in Figure 4. This figure highlights the difference of operation of these systems and demonstrates that using such a representation allows to easy detection of the systems which present technical problems.

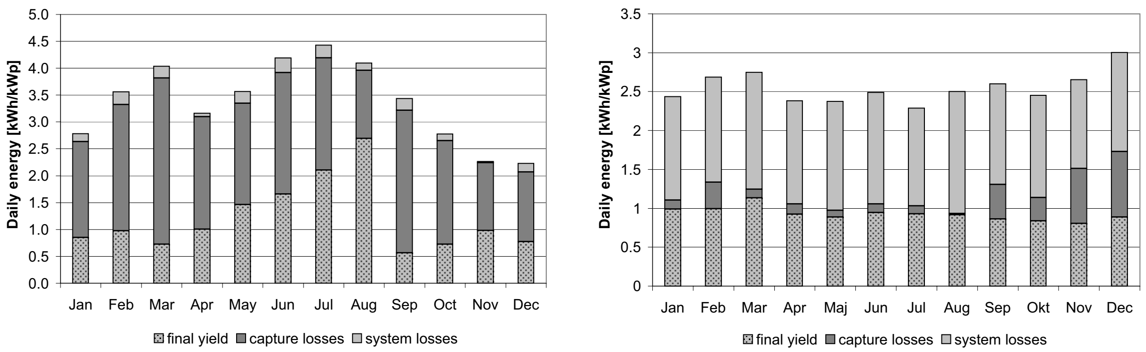

Figure 4: *Indices of performance for two systems with PR = 0.3 (UF=0.45 and UF= 0.9)*

5.4 Conclusions

When considering all the systems which do not show any problems of operation, UF and PR are proportional (Figure 5). In the best conditions UF=1, which indicates that PR=0.78 seems to be a limit for PV SAS performance ratio, at least for the considered systems.

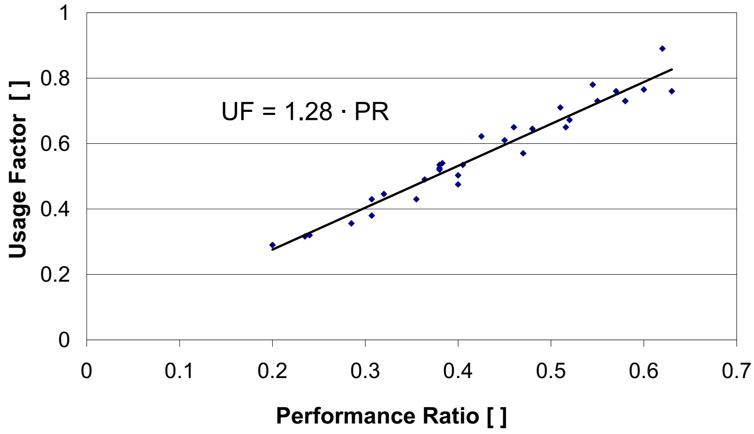

Figure 5: Usage Factor as a function of the Performance Ratio for well operating systems

Such results have been obtained from the analysis of some ten systems operational data. More reliable data are needed to ensure a statistical relevance. Nevertheless they seem very promising in terms of quick assessment of system behaviour.

The parallel analysis of two case studies (hybrid systems of about 20 kWp sharing the same architectural design) has been presented as examples of the use of such factors.

6 PROMOTING PV SYSTEMS THROUGH THEIR ADDED VALUES

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Within the PVPS programme, Task 1 (Information) under the lead of Japan has organized two international workshops (September 1999 in Sapporo, May 2000 in Glasgow) dealing with the "Added Values of Photovoltaic Power Systems". The outcome of the workshops as well as exchange of information between interested parties has led to a report, written by Dr Muriel Watt, Centre of PV Engineering, University of NSW, Sydney, Australia.

This paper focuses mainly on the added values for utilities. Following is an extract of the report IEA–PVPS T1-09:2001. The whole report can be downloaded from the PVPS website www.iea-pvps.org.

Values for Utilities

Over the past half century, central generation has been seen as the most efficient way of delivering electricity to large numbers of consumers. This resulted from the economies of scale offered by large fossil fuel and nuclear generators, combined with the availability of low cost fuels and government support for infrastructure development. However, for PV, the lower energy density of the solar resource results in optimal sizes being smaller than for fossil fuel or nuclear systems, while economies of scale are achieved by increases in production volumes rather than installation size. Smaller scale generation, connected into the electricity distribution, rather than the transmission, network is referred to as distributed generation and includes building integrated PV systems. Table 1 summarizes some of the benefits offered by distributed generation, termed "micro-power" by Lovins and Lehmann [2000].

Benefit	Description
Modularity	By adding or removing units, micropower system size can be adjusted to match demand.
Short lead time	Small-scale power can be planned, sited, and built more quickly than larger systems, reducing the risks of overshooting demand, longer construction periods, and technological obsolescence.
Fuel diversity and reduced price volatility	Micropower's more diverse, renewables-based mix of energy sources lessens exposure to fossil fuel price fluctuations
"Load-growth insurance" and load matching	Some types of small-scale power, such as cogeneration and end-use efficiency, expand with growing loads; the flow of other resources like solar and wind, can correlate closely with electricity demand
Reliability and resilience	Small plants are unlikely to all fail simultaneously; they have shorter outages, are easier to repair, and are more geographically dispersed
Avoided plant and grid construction, and losses	Small-scale power can displace construction of new plants, reduce grid losses, and delay or avoid adding new grid capacity or connections
Local and community choice and control	Micropower provides local choice and control and the option of relying on local fuels and spurring community economic development
Avoided emissions and other environmental impacts	Small-scale power generally emits lower amounts of particulates, sulfur dioxide and nitrogen oxides, heavy metals and carbon dioxide, and has a lower cumulative environmental impact on land and water supply and quality

Table 1: *Eight Hidden Benefits of Micropower [Lovins & Lehmann, 2000]*

Reduced infrastructure costs and network losses

Distributed generation can offer reduced costs for infrastructure, such as line capacity and peak load generation facilities, as well as reduced network operating and maintenance costs. It can also serve to delay or eliminate the need for network augmentation. With network costs accounting for up to 50 % of electricity bills, where retail competition has not been introduced, this is an important benefit, particularly where networks span large distances, where high load growth in some areas is leading to grid constraints or where lines are reaching the end of their expected life [Outhred & Watt, 1999]. Generation close to load centres also reduces network losses, which can be as high as 25 % of electricity distributed through long rural lines.

Reduced financial risk

Another key advantage of decentralized PV systems over traditional centralized supplies is the lower risk it offers in upgrading capacity. The ability to follow load growth more closely by adding incrementally to supply reduces the period of over-capacity which inevitably follows the installation of a large system, and hence also the period of low prices experienced until load growth catches up. In periods of uncertainty, the risks associated with under-utilized assets may add considerably to the costs. Excess new capacity can also lead to premature retirement of older plant and hence reduce the returns on previous investments. PV systems offer further risk reductions: few management overheads related to ongoing fuel contracting or legal costs and no fuel price risks [Awerbuch, 2000]. Despite these acknowledged risks, PV systems continue to be assessed from an engineering economics perspective, whereas the use of capital asset pricing models, already used as the basis for “lean” manufacturing, would provide values for the reduced risks and uncertainty, as well as for the planning flexibility, reversibility and modularity offered by PV [ibid].

There is some utility recognition of the potential cost benefits of increasing network support through distributed generation in current planning processes or in their longer-term strategic thinking. As competition, and perhaps privatization, occurs in the electricity industry, the advantages of distributed generation may be more widely recognized. In the interim, regulatory processes must ensure that distributed resources are given equal access to the network and that central generation is not favoured simply because it is the existing paradigm.

Capacity credit and peak lopping

Compared to central PV stations, decentralized systems smooth output fluctuations and provide a better match to loads, therefore providing a higher capacity value from the utility point of view. This has been verified by studies undertaken in Japan [Ohtani, 1999] which show that regional output becomes more important for decentralized systems than the output from individual systems. More work is needed to determine optimum sizes and distribution of PV systems to gain maximum network benefit, however, short-term fluctuations due to moving cloud cover could be compensated for within a 10 km radius. The impact on effective capacity over larger areas, including entire interconnected networks, needs to be assessed. Improved weather forecasting is expected to allow better forecasts of PV output and hence higher reliability of output for utility planners.

For commercial and industrial customers, the capacity value that can be placed on a PV system is as important as its energy value, since billing has a strong demand component. From a utility perspective, it is difficult to attribute capacity credit to a PV system, because of the stochastic nature of the output and hence the relatively uncertain correlation with peak demand. However, on average, solar radiation levels are very reliable, so that, where air conditioning loads contribute significantly to peak demand a positive correlation would be expected with PV output. The value of PV could therefore be higher for utilities in areas with a summer peaking load.

From the customer’s perspective, the effective load carrying capacity (ELCC) of PV can be especially high for commercial customers, with typically good matching between peak PV output and daytime air conditioning load. This correlation is not as high for residential customers in countries where peak loads are typically later in the day, but may be high for some European residential customers with daytime peak loads.

Studies in Japan [Nanahara, 1999] show that PV output between 2pm and 3pm in summer averages 31 % of rated PV capacity and for peak summer days output averages 39 % of rated capacity. Correlation levels between PV output and peak demand vary over the country, however PV output on peak summer days is consistently higher than for average summer days in all except the northern most part of Japan [ibid].

Studies in the U.S. have shown that the correlation between summer to winter peak load and effective load carrying capacity is higher than that between average irradiance levels and ELCC [US DoE, 1996]. The ELCC can exceed 80 % of PV rated output when the ratio of summer to winter peak load is greater than 1.5 [ibid]. Hence a 1 kWp PV system could be considered to have a dispatchable rating of 800 Wp. Using this approach, the US DoE has published a map showing the different PV ELCC across the US [ibid]. This map allows planners to target areas where PV would have a high value. These areas are not necessarily those with high solar radiation levels.

Perez et al [1999] have shown that the ELCC can be increased further by simple load control strategies aimed at optimizing load and PV output. They found that improvements of 10-25 % are possible for photovoltaic power systems sized at 10 % of the building load, resulting in an added value of USD 100 to 500 per kWp, depending on location, with a U.S. average of USD 300 per kWp for commercial buildings.

New business opportunities

Utilities are generally keen to take advantage of the positive customer image of utility reliability and the public interest in environmentally friendly energy sources in their development of PV businesses. Such perceptions, combined with the greater ability, compared with independent operators, to offer a variety of financial packages, and with the history of monopoly service, provides utilities with a competitive advantage in the market. Utilities have explored business opportunities in stand-alone PV systems, rooftop PV and Green Power products. Some utilities are specializing in providing renewable energy projects as a service to other utilities, to cater for green power markets or mandatory renewable energy targets. Green Power provides utilities with an opportunity to market a premium product, rather than just a commodity.

Image

Corporate positioning and image are important strategic factors for many utilities involved in competitive markets. An involvement in PV is being used by some utilities to demonstrate a commitment to the environment and as a sign that the organization is dynamic and innovative. This is demonstrated by the large number of PV images now used in the advertising or marketing materials of utilities operating in a competitive market. In a fully competitive market customers can compare utility programmes and seek justification for claims made. The initial introduction of retail competition in the US has seen a significant level of customer interest in green products. Even in countries such as Australia, where full retail competition has yet to be introduced, almost all electricity retailers now offer green products. Although PV is not the cheapest technology for utilities, most still include some PV in their portfolios because even systems as small as 1 kWp can be installed in high visibility locations, close to customers, and provide a high technology, green image.

Examples of utility programmes

In Switzerland a **"stock exchange"** model has been used successfully to promote PV installation and solar photovoltaic electricity use [Nowak, 2000]. A Solar Stock Exchange was established in Zurich in 1995, whereby PV system owners sign long-term contracts with utilities for solar photovoltaic electricity, which is in turn sold to customers (see Figure 1). By early 2000, 42 systems with 1.62 MWp capacity had been installed; 5 700 customers had subscribed, representing 2.9 % of the target population and purchasing 1.2 GWh per year of solar photovoltaic electricity. A subsequent national programme, “Energy 2000”, has resulted in 90 Swiss utilities offering solar products to 3 million customers. By early 2000, 21 000 customers had subscribed for 3.5 GWh per annum at tariffs of EUR 0.6 to 0.9 per kWh and 3.4 MWp has been installed. A mix of products, marketing and models were used, with nearly 50 % using the stock exchange model.

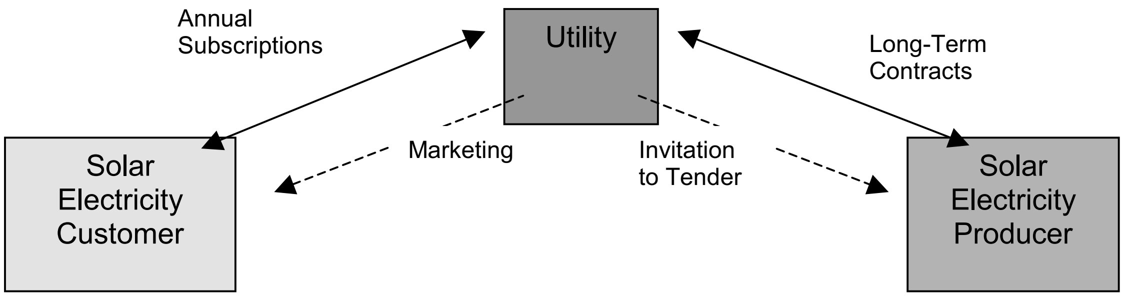

Figure 1: *The Solar Stock Exchange Model [Nowak, 2000].*

Green Power products have emerged as one means for utilities to offer differentiated products to domestic and business customers, with the intention of gaining new customers or increasing customer loyalty. Many utilities around the world now offer some form of Green Power, however, there is considerable variation between the schemes on offer and they are often offered to both contestable and franchise customers.

The growth in Green Power around the world reflects the increased focus placed on customer preferences as a result of restructuring. In many instances, the potential mobility of customers has forced utilities to look more closely at the attitudes and perceptions of customers, and to develop products and marketing approaches in response. However, Green Power can only work as a real marketing tool when customers have choice of retail supplier. Where such competition exists, Green Power programmes are proving to be an important element in customer choice and, in some US states, utilities have chosen to use State subsidies for renewables to lower the price for Green Power, sometimes to below the standard electricity tariff [Green-e Renewable Electricity Programme, 1999].

To ensure customer confidence in the programmes, the US Green-e programme provides independent certification for Green Power schemes, publishing details and ensuring that utility claims are not fraudulent. Australian schemes are certified and now require labeling to distinguish levels of greenhouse gas reduction.

The reliance on Green Power and solar stock exchange models as means of increasing renewable energy use does, however, place the burden of environmental action on customers and individuals [IEA–PVPS, 1999], without necessarily changing the structure and operation of the energy sector. Government and community acceptance of a need for a transition to sustainable energy systems is necessary before renewables can play a significant role.

Minimum buy-back rates have been introduced in some European countries and US States for renewables based electricity generally or PV specifically feeding into the grid from small generators. Typically these rates are higher than standard bulk rates which would otherwise be paid, and have been effective in stimulating the PV market, particularly when the rates are guaranteed for long enough to achieve acceptable returns on investment [Goldstein et al, 1999]. Even if they are not much higher, the availability of standard rates removes uncertainty during the feasibility phase of new projects and reduces the time and cost otherwise associated with tariff negotiations.

In an effort to stimulate local PV and other renewable energy industries and drive down costs, some areas have introduced rates that are higher than retail tariffs. In particular, so called “rate based incentives” up to 10 times the retail tariff are being used in areas of Austria, Switzerland and Germany, usually as a result of consumer demand. The rates are funded from across-the-board levies and have time or capacity limits. Compared to Green Power schemes, the investment burden is shifted from the utility to the customer. However, tariff incentives are seen by some as more sustainable means of market development than one-off capital subsidies. In particular, with returns based on electricity generated, there is a high incentive to choose low cost and high efficiency systems, while capital cost subsidies typically apply to installed capacity without regard to performance.

Net metering can be a practical way to provide transition support for small-scale grid-connected PV generators. A single meter is used to measure both the export of electricity to the grid and the import of electricity from the grid. This eases problems of market access for PV by reducing administrative costs and metering complexity. In addition to the simplicity and low cost of this arrangement, customers receive the retail rate for electricity exported to the grid until their exports exceed their imports. This in turn encourages appropriate sizing of PV installations and efficient energy use. Net metering is particularly useful once the performance of a technology is reasonably well understood, since the single meter removes the monitoring function that would otherwise be provided by a separate meter.

Typically, a cap is placed on installations qualifying for net metering, based on peak capacity installed or a percentage of electricity generated in the area. There is a move to encourage standard application procedures, as a further means of easing access, rather than using a system of individual contracts [State of Vermont Public Service Board, 1999].

Net metering is being encouraged by a resolution to the US Congress [NARUC, 1998] and has been regulated for in thirty US states [IREC, 1999]. For many utilities, net metering is seen as good marketing strategy, with minimal financial risk and the possible added value of distributed generation in grid constrained areas. It could also be a very cost effective means of reducing the need to purchase power during summer peaks, when spot prices have been as high as USD 50 per kWh. However, utilities can still apply high connection or supply charges as a disincentive.

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Annex B IEA–PVPS TASK 2 WORKSHOP PROGRAMME

Operational Performance, Reliability and Promotion of Photovoltaic Systems

Wednesday, 24 October 2001, 14:00 - 17:00 hours
17th European PV Solar Energy Conference and Exhibition
ICM International Congress Centre, Munich, Germany, Exhibition Hall

14:00 – 14:05	Welcome by the Moderator	Th. Nordmann
14:05 – 14:20	Introduction: IEA-PVPS overview & PVPS Task 2 work	U. Jahn
14:20 – 14:40	Presentation of the Performance Database	W. Nasse
14:40 – 15:40	Operational performance know-how and results of PV systems by four PV experts	
	• Large PV systems in Italy	S. Castello
	• Results and future plans for monitoring residential PV systems in Japan	K. Sakuta, O. Ikki
	• Experiences from long-term PV monitoring in Switzerland	L. Clavadetscher
	• Reliability of PV systems in Austria, lessons learned	H. Wilk
15:40 – 15:55	*Questions & Discussion on performance results*	
15:55 – 16:10	Irradiation in the built environment	N. van der Borg
16:10 – 16:25	Performance assessment for PV stand-alone systems	D. Mayer
16:25 – 16:45	Promoting PV systems through their added values	P. Hüsser
16:45 – 17:00	*Conclusions*	

Annex C LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations

ADEME	Agence de l' Environnement et de la Maîtrise de l' Energie (French Agency for the Environment and Energy Management)
AM	air mass
AMD	availability of monitored data
ANIT	Italian PV industry
a-Si	amorphous silicon
AUS	Australia
AUT	Austria
BFE	Bundesamt für Energie (Swiss Federal Office of Energy)
BIPV	building integrated photovoltaics
BMBF	Bundesministerium für Bildung und Forschung (German Federal Ministry of Education and Research)
BMWi	Bundesministerium für Wirtschaft und Technologie (German Federal Ministry of Economy and Technology)
BOS	balance of system
CHE	Switzerland
c-Si	crystalline silicon
DEU	Germany
EdF	Electricité de France (French national electric utility)
ELCC	effective load carrying capacity
EMC	electromagnetic compatibility
ENEA	Ente per le Nuove Tecnologie l' Energia e l' Ambiente (Italian Agency for New Technology, Energy and Environment)
ENEL	Main Italian electric utility
EU	European Union
FRA	France
FY	fiscal year
GCS	grid-connected systems
GWh	gigawatt hour
IEA	International Energy Agency
IEC	International Electrotechnical Commission
ISES	International Solar Energy Society
ISR	Israel
ITA	Italy
JPN	Japan
JRC	European Commission Joint Research Centre
kWh	kilowatt hour
kWp	kilowatt peak
mc	multicrystalline
mc-Si	multicrystalline silicon
MF	matching factor
MPP	maximum power point
MW	megawatt
MWh	megawatt hour
N	north
NEDO	New Energy and Industrial Technology Development Organization (Japan)
NLD	Netherlands
NOVEM	Netherlands Agency for Energy and the Environment
OECD	Organization for Economic Cooperation and Development
PLUG	photovoltaic low-cost utility generator
p-Si	polycrystalline silicon
PV	photovoltaics
PVPS	photovoltaic power systems
R&D	research & development
SAS	stand-alone systems
STC	standard test conditions
UF	usage factor
USD	United State Dollar (currency)
US DoE	United States Department of Energy
VSE	Swiss Electricity Producer and Distributor Association
VDEW	Vereinigung Deutscher Elektrizitätswerke e.V. (Association of German Electric Supply Companies)

Symbols

A_A	array area
AMD	availability of monitored data
E_A	array output energy
E_{BU}	energy from back-up
E_{CONS}	electricity consumption of the users of grid-connected systems
E_{FS}	net energy from storage
E_{FU}	net energy from utility grid
E_{II}	d.c. energy input to inverter
E_{IN}	total system input energy
E_{IO}	a.c. energy output from inverter
E_L	energy to loads
E_{TS}	net energy to storage
E_{TU}	net energy to utility grid
E_{use}	useful energy supplied by the system
$E_{use,PV}$	direct PV energy contribution to Euse
F_A	fraction of total system input contributed by PV array
F_S	solar fraction
F_d	direct use fraction
G_I	global or direct irradiance in the array plane
G_{STC}	global irradiance at standard test conditions
H_I	global or direct irradiation in the plane of the array
I_{SC}	short circuit current
L_C	array capture losses
L_S	system losses
M	monitoring fraction
MF	matching factor
O	outage fraction
P_0	nominal power at STC
PR	performance ratio
T_{am}	ambient air temperature
T_m	module temperature
Y_A	array yield
Y_f	final yield
Y_r	reference yield
UF	usage factor
V_{OC}	open circuit voltage
η	efficiency value
$\eta_{A,mean}$	mean array efficiency
η_{A0}	nominal array efficiency at its rated power P_0
η_I	energy efficiency of the inverter
η_{tot}	overall PV plant efficiency

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Annex E PRODUCTS

Information about available reports and other materials can be obtained from the websites.

WEBSITES

PVPS

http://www.iea-pvps.org

Task 2

http://www.task 2.org

PERFORMANCE DATABASE

The key product of Task 2 is the Performance Database. This database is designed to provide PV experts and other target groups as well as other Tasks of PVPS with suitable information on the operational performance, reliability and costs of PV systems and components. The database programme can be obtained from the Operating Agent on CD-ROM or downloaded from the Task 2 website.

ANALYSIS REPORT

A detailed report on the Analysis of Photovoltaic Systems, April 2000, summerizes the analysis of more than 260 PV systems located worldwide and integrated in the Task 2 Performance Database, illustrates the operational behaviour of the PV systems by suitable graphics and presents the detailed results in normalized and standard form. The Report IEA–PVPS T2-01:2000 can be ordered from the Operating Agent on paper (230 pages) or can be downloaded from the PVPS and Task 2 websites.

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Annex F PERFORMANCE DATABASE SPECIFICATIONS

IEA International Energy Agency

Photovoltaic Power Systems Programme

Performance Database

The Performance Database of Task 2 of the Photovoltaic Power Systems Programme (PVPS) of the International Energy Agency (IEA) is designed to provide experts, industry, utilities, manufacturers, system designers, installers and schools with suitable information on the operational performance, reliability and design of photovoltaic (PV) systems and components. The benefit of the Performance Database lies in sharing technical information focusing on long-term performance and reliability of PV systems and providing tools for practical and educational purposes.

Database programme

- CD-ROM at price of 20 EUR
- Internet download for free at www.task2.org (45 MB)
- English language
- First release in July 2001
- Last update in March 2002
- Financed by the German Federal Ministry of Economy and Technology (BMWi)

Database contents

- Information on 316 photovoltaic systems in IEA countries worldwide
- Grid-connected, off-grid and hybrid photovoltaic systems of 1 kWp up to 3 MWp
- General system information (size, system type, mounting, location, cost, photo)
- System configuration and component data
- Monitoring data (values of monthly energies, irradiation and temperature)
- Calculated data (monthly and annual values of performance indicators)

Programme specifications

- PC of 64 MB RAM, 100 MB hard disk space
- Windows 95/98, NT4.0 or Windows 2000
- Excel 97/2000 for reports and data exports
- Filter, selection and easy navigation through the database
- Import and export tools

Information and CD-ROM are available from:

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Website: www.task2.org

Task 2 — **Operational performance, maintenance and sizing of photovoltaic power systems and subsystems**