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"The Activities of ESTI (European Solar Test Installation) in the Fields of PV Testing and Monitoring"

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Introduction:

ESTI (European Solar Test Installation) has been set up to give technical support to PV development by

- contributing to the **development of standards** for PV devices
- **calibrating reference devices**
- carrying out **module performance and qualification tests**
- executing **on-site power measurements** on complete PV plants
- **monitoring** the long-term performance of PV installations

1.Performance and Qualification Tests on Modules

The main objectives of this activity are:
1. to assess the relative performance of modules and
2. to identify design features and environmental factors limiting module life.

The following techniques are used:
- Electrical Measurements:
  -- Tracing of Current-Voltage(I-V-)Characteristics at STC, NOCT and "Low Irradiance"
  -- Insulation Tests
- Climatic Simulations:
  -- UV Irradiation Test
  -- Hot-Spot Endurance Test
  -- Damp Heat Longterm Endurance
  -- Thermal Cycling
  -- Humidity Freeze
- Mechanical Resistance Tests:
  -- Robustness of Termination
  -- Twist Test
  -- Mechanical Load
  -- Hail Test

This testing activity started already in 1978 and proceeded in parallel with the development of test specifications, in close cooperation with PV specialists of other countries and with standards organisations such as IEC. Until 1984 crystalline modules were tested according to Spec.501, then according to Spec.502, while now (since 1989) ESTI uses its Spec.503 which is an implementation of a proposed standard of IEC (TC82/WG2). For thin-film modules ESTI has proposed its Spec.701 to be accepted as IEC standard.
Since 1978 ESTI has tested about one hundred types of modules.

2.On-Site Power Measurements on PV Arrays ('Acceptance Tests')

These measurements are performed with the aim

- to verify, for new PV installations, that the contractual terms concerning the nominal power of the PV plant are met,
- to detect mismatch, module or wiring failures and ground faults, and
- to detect ageing effects (module degradation) by remeasuring PV plants after several years of operation.

The measurement procedure is as follows:

1. Trace the current-voltage characteristic of each subarray by means of a portable load of sufficient power handling capability such as a capacitor load, and record simultaneously in-plane irradiance and ambient temperature.
2. Extrapolate the measured characteristic to STC (*Standard Test Conditions*, i.e. in-plane irradiance G_I of 1000 W/m^2 with a spectral distributions corresponding to air mass 1.5, cell temperature of 25° C), determine the maximum power at STC ($P_{max,STC}$) of each subarray from its extrapolated characteristic and that of the plant as the sum of the $P_{max,STC}$'s of all subarrays.

ESTI has developed its first capacitor type portable load and the extrapolation method in 1982. It has carried out from 1982 to 1984 on-site measurements on 14 PV plants (in the range between 30 and 300 kW_p, that were built in the frame of the PV Pilot Program of the European Community) as part of the official acceptance procedure (*acceptance tests*). Since then it has continued with such measurements on specific request (new and old plants). Thus, it has performed such measurements on about 1.5 MW_p of installed array power.

3. Monitoring PV Projects

The main objectives of this activity are:

- to demonstrate that PV systems are a reliable energy source,
- to identify weak system components,
- to improve systems design methods (optimising a PV plant for given site and application),
- to identify operational procedures (such as. battery and load management) that optimise the efficiency of an existing installation, and
- to establish evaluation methods for comparing PV systems with other energy sources in economic terms.

In order to facilitate the implementation of PV monitoring and to produce sets of data that can be easily exchanged, evaluated and compared ESTI coordinates the work of a group of experts (European Working Group for PV Plant Monitoring). This group has produced (and updates) the *Guidelines for the Assessment of Photovoltaic Plants*, which consist of two documents:

1. Document A: *Photovoltaic System Monitoring*, which specifies
   - the type of data logging at the site (analytical or global),
   - the set of parameters and measurement procedures, and
   - the modalities for data transfer to the collecting center (medium and format);
2. Document B: *Analysis and Presentation of Monitoring Data*, which gives recommendations for the evaluation of these data, defining 'Figures of Merit' and specifying a standard format for periodic summary reports.

ESTI started with its activities in the field of PV Plant Monitoring within the frame of the Pilot Plant Project of DG XII, the General Directorate of Commission of the European Communities (CEC) responsible for research. The main monitoring period in this context was 1984-1986, though some plants continued to send data for a longer time. Since monitoring was not mandatory, only 8 of the 15 plants sent data.
Since 1985 ESTI collects the monitoring data from the PV Demonstration Projects sponsored by DG XVII, the General Directorate of CEC responsible for energy. For these projects 2 years of monitoring are mandatory (with analytical monitoring for all plants > 5kW).
The cooperation with DG XVII started in 1983 with the participation in the selection of the PV Demonstration Projects and the preparation of the Guidelines. Actual monitoring of the PV projects initiated at the end of 1985; so far more than 500 'station_months' of data from analytical monitoring have been collected, analysed and stored. Thus ESTI disposes of the largest collection of operational data from PV plants.
Results of this activity are published in periodic reports jointly by DGXVII and ESTI. In addition, the *European PV Plant Monitoring Newsletter* reports on the progress in this field.

Attached Documents

1. *On-Site I-V Measurements on Large PV Arrays*
2. Guidelines for the Assessment of Photovoltaic Plants:
   Document A: *Photovoltaic System Monitoring*
   Document B: *Analysis and Presentation of Monitoring Data*

On-Site I-V Measurements on Large PV Arrays

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1.INTRODUCTION:

Since 1982, when we performed the first on-site array measurements on the 50 kW PV pilot plant in Aghia Roumeli (Crete), we remained always active in this field. The first groups of measurements (cf. /1/ and /2/) were part of the acceptance procedure for the installations of the DGXII PV pilot program; they were performed shortly after completion of the plants, with the aim to verify that the rated power of the array field reached the contractual value. 14 PV installations within the power range of 30 - 300 kW_p were measured (1982 - 1984).
In 1988 we remeasured some of the pilot plants already studied in 1982-1984 in order to check if degradation in array output had taken place during several years of operation of these plants. Other recent tests were again part of the start-up procedure for new installations. The total installed power of all installations measured by ESTI since 1982 comes close to 1.5 MW_p.
The method we used in all these measurements consists in scanning of the I-V characteristics of a subarray by the variation of a load connected to the subarray at a suitable connection point, usually at the main switch box in the control room, so that cable and diode losses are taken into account in the resulting I-V curves. To eliminate the influence of the particular values of irradiance and temperature and to be able to compare measurements performed on the same array under different ambiental conditions all scans have to be extrapolated to the same *standard test conditions* (STC, i.e. in-plane irradiance G_I of 1000 W/m^2 with a spectral distribution corresponding to air mass 1.5, cell temperature of 25^o C)). Here we will discuss details of the measurement procedure and the extrapolation method together with some remarks concerning our actual experience.

2. MEASUREMENT PROCEDURE:

2.1 The Load:

We used for the I-V scans a capacitor load, first mentioned in this context by CULL and FORRESTIERI /3/ and then by COX and WARNER /4/. Our earlier versions of such a load, as described in /1/ and /2/, have been replaced since summer 1988 by a commercial product, designed and build according to our recommendations by STELLA Solartechnik. It is a micro-processor controlled instrument with a number of functions that can easily be

selected by means of function keys and a menu interface. On each scan 128 I-V points are sampled by two 10-bit A/D-converters and collected in a build-in RAM memory which can hold up to 20 scans. Data may later be read out to a computer via a standard serial interface (RS-232). Each scan is also visualised immediately on a liquid-crystal display so that "bad runs" are detected in time to repeat the measurement. The capacitor with its associated thyristor, the shunt and the voltage divider are all mounted in a plug-in unit which may be changed in order to adopt the instrument to the wide range of voltage and current levels encountered.
Recently, portable battery-powered digital oscilloscopes such as the Philips-Fluke PM97 'Scopemeter' have become available, and it is very easy to use them together with a home-built capacitor load (c.f. figure 1). Again, the data can be transferred to a laptop or palmtop computer via the RS232 interface and finally analysed by programs such as LOTUS-123.
The capacitances should chosen in such a way that scan times are always longer than 10 ms; thus, the recorded characteristics are quasi-static and not perturbed by carrier lifetime effects.

2.2 The Measurement:

The subarray to be measured is disconnected from the rest of the system and connected to the capacitor load. At the moment the scan is triggered we also read the short-circuit current from a calibrated reference device (cell or mini-module, or even a calibrated module) of the same type (spectral response and encapsulation) as the modules under test. The reference device must be mounted in parallel to the subarray (and as close as possible to it). Dividing this current value by the calibration factor of the reference device we get the effective in-plane irradiance G_I at the moment of the scan. We also record the ambient temperature T_{am} at the time of the measurement.

3. EXTRAPOLATION TO STC:

We use the extrapolation procedure presented in /2/: each current-voltage pair (I_{meas}, V_{meas}) on the actual scan is transformed into a corresponding pair (I_{STC}, V_{STC}) on the extrapolated characteristic by

(1) $I_{STC} = I_{meas}(G_{STC}/G_I)$

(2) $V_{STC} = V_{meas} + DV - (I_{meas} - I_{STC})\, R_s$

where DV is the difference between the observed $V_{oc,meas}$ and $V_{oc,STC}$, and R_s is the series resistance of the array and the cabling; it is determined by extrapolating low-irradiance scans (say, at 600 W/m^2) to the same STC curve obtained from high-irradiance scans where G_I is close to G_{STC} (1000 W/m^2) so that the R_s-term may be neglected. The extrapolation scheme given by Eqs.(1) and (2) consists simply of a re-scaling (by the factor G_{STC}/G_I) of the I-axis and a displacement of the curve by DV along the V-axis; it needs no reference to any temperature measurements provided that $V_{oc,STC}$ is known for the subarray under test. This is due to the fact that all voltage temperature dependence is included in the DV-term while for crystalline Si-devices the current temperature coefficient is so small that even for a temperature difference of 10° C between the array and the reference device current temperature effects would cause less than 1% error.

4. DETERMINATION OF $V_{oc,STC}$:

We have proposed a method /5/ to determine $V_{oc,STC}$ from a set of simultaneous recordings of ambient temperature T_{am}, in-plane irradiance G_I and open circuit voltage V_{oc}. First, one should note that DV may be written as the sum of two terms

(3) $DV = DV_G + DV_T$

where DV_G contains the dependence of V_{oc} on irradiance G and DV_T the temperature effects. Denoting the thermal voltage nkT/q by V_T, the voltage temperature coefficient and the effective junction temperature of the array by ß and T_j, respectively, and the reference temperature (usually 25° C) by T_{STC}, we can express these terms in the form

(4) $DV_G = V_T \ln(G_{STC}/G_I)$

(5) $DV_T = ß(T_j - T_{STC})$

If we now assume a linear relationship between the effective junction temperature T_j of the subarray and the in-plane irradiance G_I:

(6) $T_j = T_{am} + kG_I$

we can rewrite equation (5) in the form

(5a) $DV_T = ß(T_{am} - T_{STC}) + ßkG_I$

and thus finally, with $C_G = ßk$ and $DT = T_{am} - T_{STC}$,

(7) $V_{oc,STC} = V_{oc} + DV$

$= V_{oc} + V_T\ln(G_{STC}/G_I) + ßDT + C_G G_I$

The set of the coefficients V_T, ß and C_G is either chosen by a least square procedure or calculated from module data such as NOCT etc.
As these coefficients are proportional to the number of modules in series, we find it convenient to factor out $V_{oc,STC}$ and to use the reduced coefficients

$a = V_T/V_{oc,STC}$, $b = ß/V_{oc,STC}$, $c = C_G/V_{oc,STC}$

which are constants for a given type of module. For many types of modules we could use the following set of coefficients:

$a = 0.06$, $b = 0.004$[/° C], $c = 0.00012$[/(W/m^2)]

In practice we start our measurements in the morning hours at low irradiances (i.e. with G_I in the range of 200 - 500 [W/m^2]) by recording the subarray V_{oc}-data together with irradiance and ambient temperature. When the irradiance G_I reaches c. 600 [W/m^2] we start with the I-V scans.

However, each I-V scan also gives us a V_{OC}-value together with the irradiance. Since we also record T_{am} during the I-V scans we can use these data also for the determination of $V_{oc,STC}$. Finally, when in the afternoon irradiance values drop below 600 [W/m^2], we stop the I-V scans but record another set of V_{oc} data. We determine the final $V_{oc,STC}$ for a subarray by the arithmetic mean of all the values found for the subarray by the use of equation (7).

Using this mean value of $V_{oc,STC}$ of the subarray we determine for each scan on that subarray the corresponding $DV = V_{oc,STC} - V_{oc,meas}$ and use this value in the extrapolation.

5. PRACTICAL EXPERIENCE:

The guiding principle in the development of the measurement and extrapolation techniques has been the compatibility with indoor (simulator) measurements: The extrapolated data from outdoor measurements on modules have to agree (within the experimental errors) with the corresponding data obtained for the same modules in simulator measurements. By using suitable reference devices calibrated in the same way as those used in simulator measurements we eliminate the influence of the spectrum; also, we are sure that our irradiance standards are the same. Our experience has shown that the way we correct for temperature (via V_{oc}) is reliable.

Another check on the validity of the techniques presented here is the requirement that the data obtained on the same arrays under different ambiental conditions must all extrapolate to the same set of STC-values. Taking the fluctuation of the extrapolated data about their average as an indication of the reliability of the extrapolation method we can say that $P_{m,STC}$, the maximum power value on the extrapolated I-V curve, is determined within ca. 3%, even when we compare measurements at low irradiance (600 W/m^2) with those at very high irradiance (higher than 1100 W/m^2). The situation is even better with $V_{oc,STC}$: While under fluctuating irradiance conditions (clouds) thermal non-equilibrium effects cause individual values to deviate from the mean by several percent, other data, in particular those extrapolated from very low irradiance levels (150 - 250 W/m^2) are rather stable so that the statistical error in the average $V_{oc,STC}$ normally is only c. 1%.

We believe that all methods that need module temperature measurements for extrapolation to STC are impractical to apply to large array fields, in particular if the arrays are of difficult access (mounted on roofs or high supports) or scattered over a wide area. The use of DV as an alternative to all temperature corrections is more reliable and far more convenient.

In /2/ we recommended to restrict array power measurements to irradiances above 600 W/m^2. It seems that this is a very conservative approach as we found out during a period of bad weather conditions when we scanned the 30 subarrays of the Terschelling pilot plant under overcast conditions, with irradiances ranging from 140 to 340 W/m^2. From these scans we obtained an extrapolated power of 42.2 kW_p. On the last day finally the sun appeared and we could perform the scans with irradiances between 700 and 1020 W/m^2 from which resulted an extrapolated power of 43.4 kW_p. Thus even in this extreme case the two power values differed only by 3 %.

Normally, however, we still restrict our I-V measurements to irradiances above 600 W/m^2 since this threshold has not unduly limited the time available for our measurements. On the other hand, a threshold of 800 W/m^2 would have made it impossible on different field trips to complete the measurement program within the time available to us.

Under good weather conditions usually we can perform 20 scans in less than 20 minutes; then we have to download the data to our laptop computer before we can go on. Under such conditions all subarrays even of a 100 kW_p field can be repeatedly scanned within a single day. But often one has to wait for clouds to pass between one scan and the next, and under these circumstances it is important that the irradiance limits are not too restrictive.

6. CONCLUSION:

When we presented our first on-site measurements in /1/ and /2/ the techniques summerised here were new and to a large degree experimental. Now they have matured and can be considered to be routine measurements. Their value as an extremely powerful diagnostic tool, in particular for large installations, where unrecognised faults can lead to considerable power losses, has become evident to many plant managers. A similar development has taken place in the USA (c.f. RISSER /6/). Guidelines have to be developed now to help newcomers in this field to obtain correct results in a minimum of time.

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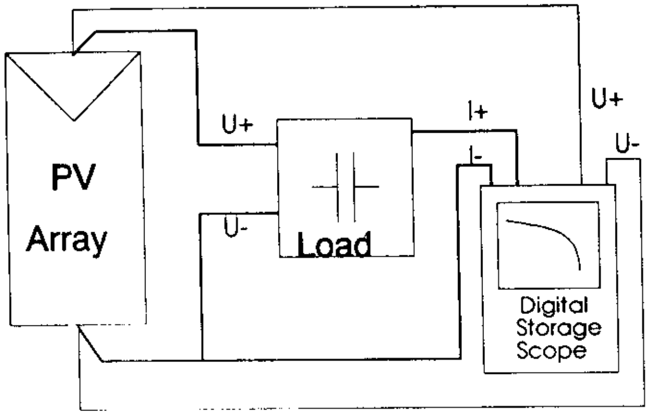
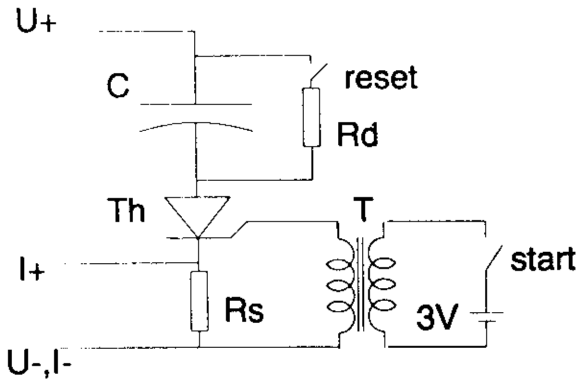


a) Schematic Overview of PV-Array I-V-Measurements with Capacitor Load and Digital Storage Scope



b) Schematic Drawing of the Capacitor Load

Fig.1: I-V Measurements by Means of a Capacitor Load

Commission of the European Communities
Joint Research Centre — Ispra Establishment

Guidelines for the Assessment of Photovoltaic Plants

Document A

Photovoltaic System Monitoring

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PREFACE

This document has been prepared by the Joint Research Centre of the European Communities, Institute for Systems Engineering and Informatics (ISEI), sector ESTI (European Solar Test Installation), Ispra (ITALY), with technical support from the European Working Group on PV Plant Monitoring and taking into account recent recommendations of IEC/TC82/WG3. The recommendations given in this document have been developed to support the PV Demonstration Programme and the THERMIE Programme of the Commission of the European Communities Directorate General for Energy (DG XVII). However, their use by others is encouraged.

For further analysis and presentation of these data reference should be made to Document B of these Guidelines. ESTI would welcome comments on this document and suggestions for improvement.

Contents

ANNEXES

1 INTRODUCTION

Data obtained during the operation of a photovoltaic power plant are of interest for judging whether the design goals have been met. They are also of importance for a general assessment of the potential of PV-technology, and thus for the future use of such installations. Finally, they should provide a data base for the improvement of PV system design and operation.

To obtain sufficiently complete sets of data for such purposes requires rather detailed or "analytical" monitoring in accordance with the requirements set out in these Guidelines. In general, unless otherwise agreed, analytical monitoring will be applied for at least 24 months for all PV installations with peak power of 5 kW or more.

In view of the cost involved in analytical monitoring, sufficient evidence for a general assessment of the performance of a PV installation may be obtained by determining the overall energy balance from regular readings of suitable counters. This procedure, referred to as "global" monitoring, will in general be applied for all PV installations with peak power less than 5 kW.

For some small installations, however, it may be appropriate to apply analytical monitoring for a few months only and then revert to global monitoring for the remainder of the monitoring period.

The treatment of the large amount of information collected for monitoring purposes, with the aim of making reliable comparisons between different stations, requires the adoption of a commonly agreed minimum set of quantities to be measured as well as standard recording techniques. These guidelines give the information which is necessary for the implementation of such monitoring systems.

2 REQUIREMENTS FOR ANALYTICAL MONITORING

2.1 Parameters to be Recorded

2.1.1 Main System

An automatic data acquisition system is required for analytical monitoring. This may be achieved by a dedicated computer with suitable peripherals and programs or a data logger capable of recording the data on the required medium in the correct format. Recommendations for the selection of automatic data acquisition equipment are given in Annex B.

The minimum set of parameters to be monitored is listed in Annex A, Table I, with symbols and units. The required accuracies are stated in the footnote to that table. The corresponding points of measurement are indicated in Annex A, Fig.1. It may be necessary to record additional parameters according to the requirements of a particular project.

Apart from the meteorological data (including temperature) all parameters are currents, voltages or powers characterising the operation of the system (consisting of the PV field and the associated loads, power conditioners, battery storage etc.).

In general, only aggregate values of each parameter are required: for example, if currents or voltagess of subfields of the total array field are separately measured, only their sums should enter the final monitoring record as I_A, V_A; if several DC-loads are present, the total current to all these loads gives $I_{L,DC}$. The AC power supplied to AC loads from an AC backup generator should be recorded as $P_{BU,AC}$. The DC current supplied to the storage battery or to DC loads from a DC backup generator (or through a rectifier from the grid or from an AC backup generator) should be recorded as $I_{BU,DC}$. If preferred, DC power values may be calculated, stored and recorded.

The AC power measurements may be performed directly by analog techniques and the resulting power signal digitized by the A/D-interface of the data acquisition system (computer or data logger).

All numerical data should be recorded on data storage at intervals t_r (*recording period*. t_r should normally equal 1 hr if averages over 1 minute (or shorter) samples are taken. However, if such averaging is not possible, instantaneous samples recorded at 10 minute intervals are acceptable; in this case t_r will be 10 minutes.

2.1.2 Back-up System

It is recommended that in addition to the main data acquisition system, a simple independent system with energy meters be installed, to record the solar input by a calibrated reference device (G_I), electrical energy consumption E_L and in case of grid-connected systems energies delivered to the utility E_{TU} and taken from the utility E_{FU}. In order to obtain long term data on system performance it is also recommended that this simple back-up system continues its operation after the end of the contractual monitoring period.

2.2 Format of Records

The data should be recorded or copied off-line in the format given in Annex C on MS-DOS 5.25" or 3.5" floppy disks.

Under special circumstances, other recording media or direct transfer of data by satellite, computer network or telephone line may be accepted subject to agreement between the parties concerned.

All data should be written in directly printable form (ASCII). The details of the recording format are given in Annex C. If data compression is used either the data should be *auto-decompressive* (.EXE) or the decompression routines should be provided together with the first set of data.

3 REQUIREMENTS FOR GLOBAL MONITORING

3.1 Parameters to be Recorded

A manual system of recording data is appropriate for global monitoring. The minimum set of parameters to be monitored is listed in Table II, Annex A, with symbols and units. The required accuracies are stated in the footnote to the table.

The cumulative readings of the listed parameters should be recorded manually at intervals not exceeding one month and preferably much shorter (daily or weekly if possible).

3.2 Format of Records

The cumulative data should be entered onto standard record sheets. A suggested format is given in Annex F.

4 DATA PROCESSING

4.1 Submission of Data to the JRC

All recordings (covering *reporting periods* τ of not less than one month and not more than three months should be sent to the JRC Ispra together with information helpful for the interpretation and evaluation of the data. This information may be given in a note or a *README*-file in plain ASCII text on the data diskette. The suggested pro-forma for the covering note is given in Annex D. In particular, if the recording format or data sequence differs from that of Annex C the recording format used must be described in detail in that note.

In addition, with the first set of records (if not previously submitted), a data sheet setting out basic information relating to the plant should be sent to the JRC. The suggested pro-forma for the data sheet is given in Annex E.

4.2 Data Processing at the JRC

The data received by the JRC from stations with analytical monitoring will be entered into the main computer of ESTI for analysis and evaluation, including the preparation of a report (as specified in Document B, "Analysis and Presentation of Monitoring Data"), summarising the main results for that period; a copy of this report is sent to the station manager. The data files will be kept online and also stored for backup, and they are accessible via public computer networks to all authorized users.

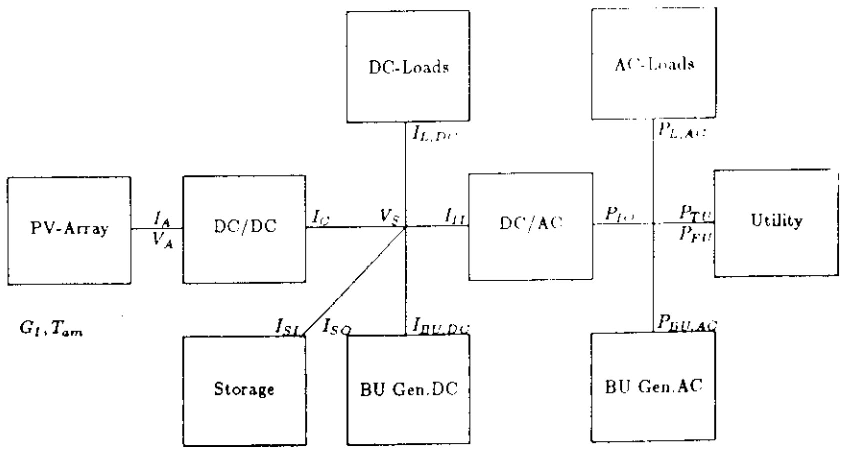
For all stations (with analytical or global monitoring) ESTI will also produce intermediate summary reports covering periods of six months or more, and final reports at the end of the monitoring period. These intermediate and final reports will be generally available.

Annex A — Recorded Parameters

TABLE I: Recorded Parameters for Analytical Monitoring

PARAMETER	SYMBOL	UNIT
Irradiance, total (array plane)	G_I	W/m^2
Ambient temperature in the shade	T_{am}	$^\circ C$
Array output voltage	V_A	V
Array output current (total)	I_A	A
Converter output current	I_C	A
Current input to storage battery	I_{SI}	A
Current output from storage battery	I_{SO}	A
dc line voltage (battery voltage)	V_S	V
Current to all dedicated dc loads	$I_{L,DC}$	A
Inverter/rectifier dc current (+/-)	I_{II}	A
Inverter/rectifier ac power (+/-)	P_{IO}	kW
Power to all dedicated ac loads	$P_{L,AC}$	kW
Power to the utility grid	P_{TU}	kW
Power from the utility grid	P_{FU}	kW
Power from auxiliary ac generator	$P_{BU,AC}$	kW
Current from auxiliary dc generator	$I_{BU,DC}$	A
Non-availability to load	t_{NAV}	hr

POWER FLOW DIAGRAM



NOTES:

1. All data are hourly sums or means.
2. The total irradiance G_I should be measured with a crystalline silicon reference device. The type shall be qualified for durability by tests similar to those laid down in EC Spec.503 for modules (or equivalent). The calibration shall be carried out (using one of the procedures laid down in EC Spec.103) to AM 1.5 total sunlight in accordance with IEC 904-3 (1989). Special attention should be given to the precise alignment of the reference device with the array plane.
3. T_{am} should b determined to within ±2°C and the electrical data to within ±2% f.s.
4. The energy consumed by the data acquisition system should be considered as part of the external load and not as internal loss (i.e. included in $I_{L,DC}$ or $P_{L,AC}$).
5. Where applicable parameters relating to product flows should be also recorded (e.g. pressure head and pumped volumes in the case of pumping systems)

TABLE II: Recorded Parameters for Global Monitoring

PARAMETER	SYMBOL	UNIT
Irradiation, array plane	H_I	Wh/m^2
Potential array output energy	E_P	kWh
Array output energy	E_A	kWh
Energy to loads	E_L	kWh
Energy to utility grid	E_{TU}	kWh
Energy from utility grid	E_{FU}	kWh
Energy from auxiliary generator	E_{BU}	kWh
Non-Availability to load	t_{NAV}	hr

NOTES:

1. All data are sums over selected periods the duration of which should be indicated.
2. The irradiation H_I should be measured with a (crystalline silicon) reference device. The type shall be qualified for durability by tests similar to those laid down in EC Spec.503 for modules (or equivalent). The calibration shall be carried out (using one of the procedures laid down in EC Spec.103) to AM 1.5 total sunlight in accordance with IEC 904-3 (1989). Special attention should be given to the precise alignment of the reference device with the array plane. If potential array energy is determined directly (by a method that must be described) the irradiation H_I need not be recorded.
3. Potential array energy is understood as the maximal energy that could have been extracted from the array under the given irradiation conditions. It might be estimated from in-plane irradiation H_I and nominal array efficiency or from the sum of the array output energy during normal operation and the available but unused energy during periods when the battery is fully charged and consumption is low. It may also be recorded directly if one string of modules is permanently attached to the battery and its output is monitored separately.
4. The electrical data shall be determined to within ±5% f.s.
5. Instead of E_A, E_P, E_L and E_{BU} the time integral of the corresponding currents $[Ah]$ may be recorded and energy values deduced using the nominal battery voltage. However this should be avoided as it will systematically underestimate E_A and E_P, and overestimate E_L and E_G.
6. The 'Non-Availability to Load' parameter shall record the cumulative time that power is not available at the load terminals, not the time the load is switched off. If this time is not measured directly by the monitoring system it should be estimated by the user.

ANNEX B

RECOMMENDATIONS FOR SELECTION AND INSTALLATION OF DATA ACQUISITION SYSTEMS

B.1 Selection of Systems for Analytical Monitoring

The following recommendations relate to microprocessor-based control and/or data acquisition systems and are based on experience gained from the operation of existing photovoltaic plants:

1. The system should be easy to use. It should be reprogrammable on site, either with a dedicated computer terminal or a 'laptop' portable computer.
2. Technical support for the hardware and software should be available and this should not be limited to individual suppliers.
3. The hardware and software should all be properly documented. In the case of software, there should be a user's manual and a programmers's manual. The purpose of the documentation is to reduce the problems associated with changes in personnel and to permit improvements in system design.
4. An inventory of spare parts should be kept on site. Standard cards should be available as spares. A list of suppliers of cards and transducers should also be available on site.
5. The system must be sufficiently rugged to withstand the environmental stresses encountered during its operation.
6. Its average power consumption should be low (typically less than 5-10 W).

B.2 EMC (Electromagnetic Compatibility)

RF energy ('noise') may be conducted down or up DC cabling and transmitted as electromagnetic interference, causing malfunctioning of electronic components and errors in monitored data records. The parasitic signals may come from outside, induced in wires, or they may be internal in origin, coming for example from power conditioning, electronics for lighting tubes and other switching devices.

Due account needs to be taken of such problems in the design, testing and protection of both global and analytical monitoring systems. Practical recommendations include:

- the use of twisted and shielded wires
- the avoidance of ground loops in the shielding
- the avoidance of coupling between power cables and signal wires
- the use of separate termination boxes for power cables and signal wires.

If the system is sensitive to noise, protective devices such as filters, diodes, varistors and, if necessary,Faraday shielding, should be installed.

The signal lines should be protected against overvoltages induced by nearby lightning strikes. Special attention should be given to long data lines for external sensors and to telephone lines.

ANNEX C

RECORDING FORMAT

The results of a recording period t_r (1 hour if averages over one-minute samples are taken, or 10 minutes if no averaging is used) form a data group. Each data group is subdivided into records, comparable to lines in printing. Records are separated by a carriage return ('CR'=ASCII(13)), or a linefeed ('LF'=ASCII(15) or both. Each record is built up of individual fields, separated by a comma. The record length must not exceed 72 characters.

All data are written in ASCII code. Since the comma (“,” =ASCII(44)) is used as a field separator, all data can be presented in free-field format without the necessity of keeping leading zeros or spaces, as signed integers or decimal fractions, with the stop (“.” =ASCII(46)) used as the decimal point. So-called scientific notation (E-notation) is not permitted. If any field in the format of a record (given below) is not applicable or data are not available for it, it has to be indicated as an empty field by its final comma following directly the preceding one. However, all commas directly preceding the end-of-record should be suppressed. Thus, if in data record 2 only the 4th and the 6th item is available, that record should be written as:

2,,,item 4,,item 6'CR'

To provide a maximum of flexibility for each installation to record additional data of its own choice, the number of records per data group may vary. Each data group starts with a header record of the following form:

HEADER RECORD: % Station% Date,Time,Comments

where "Station" is the name of the site, of which only the first four letters are mandatory (full length is permitted), Date specifies the day of the measurement in the form dd-mm-yy (here leading zeros must be written), and Time the moment of recording in the form hh.min. The time of recording is the time at the end of the hour in which measurements were taken, or the instant of recording if no averaging is used. (Time always refers to the true zone time, not to legal or daylight saving time). In the case of hourly data recording, the space allocated for comments may be used to record the times of switching events (e.g. switching from load to battery or switching in parallel inverters) in a code devised by the installation manager. Other comments may be included at the discretion of the installation manager. Thus two examples of headers are:

% NICE% 03-05-84,15.33

% FOTA% 25-03-85,13.15,EXTENDED RUN

The header record is followed by up to 9 data records, distinguished by their record number, which is the first item of each record. The symbols used are those given in Table I. Data record 1 contains the meteorological data and those of the PV field - including the battery storage - while data record 2 shows the currents, voltages and powers at the consumer level; data records 3 to 9 are at the free disposal of the installations (or may be absent). The data in records 3 to 9 is considered proprietary information.

DATA RECORD 1: $1, G_I, T_{am}, V_A, I_A, I_C, I_{SI}, I_{SO}, V_S$

DATA RECORD 2: $2, I_{L,DC}, I_{II}, P_{IO}, P_{L,AC}, P_{FU}, P_{TU}, P_{BU,AC}, I_{BU,DC}$

ANNEX D

COVER SHEET FOR MONITORING DATA

(to be submitted to JRC with each set of data)

CEC PROJECT NUMBER: SE..../..../... DISKETTE REF:..........

REPORTING PERIOD: .... to ....

1 **Name of Plant:**...

2 **Readings of back-up counters:**

	start date	end date	cumulative	energy for period
G_I	....	....	....	....
E_L	....	....	....	....
E_{TU}	....	....	....	....
E_{FU}	....	....	....	....

3 **Information on system operations during reporting period:**

3.1 SOLAR ARRAY *(Cleaning, changed tilt, replaced modules, ...)*

3.2 SYSTEM COMPONENTS *(Faults in controls, inverters, batteries, ...)*

3.3 UNUSUAL WEATHER *(Lightning, snow, hail, floods, ...)*

3.4 UNUSUAL LOADS *(System not in use, extra use, ...)*

3.5 MONITORINGS SYSTEM *(Re-calibrations, down-times, ...)*

3.6 OTHER SPECIAL EVENTS / COMMENTS ON DATA

4 **Data Format:**
☐ as specified in this document, Annex C
☐ as given below

Contact for further information:

Name: ....
Address:

Tel: .... Fax: ....

Completed by: .... Date: ....

ANNEX E

SUMMARY DATA SHEET FOR PHOTOVOLTAIC INSTALLATIONS

(to be submitted to JRC with the first set of Monitoring Data)

CEC PROJECT NUMBER: SE..../..../....

1. Name of Plant: ....
   (Latitude: .... Longitude: ....)
   Nearest Town/City: .... Distance from Plant: ......km
   Nearest Meteo Station: .... Distance from Plant: ......km
   (Refer to European Solar Radiation Atlas (1984) ISBN 3-88585-194-6)
2. Nominal PV array rating*: .... kWp; Nominal module rating: ....Wp
   Module Manufacturer and Type: ....
   Total Area of Array: ....m^2
3. Battery Bank: Nominal capacity*:.....Ah (10 hr) Nominal Voltage V
   Battery Manufacturer and Type: ....
4. Inverter Nominal Rating*: ....kVA Number of units installed:...
   Inverter Voltages: Input .....V; Output V
   Inverter Make and Type: ....
5. DC/DC Converter Nominal Rating*: ....kW Number of units installed:...
   DC/DC Converter Voltages: Input .....V; Output V
   DC/DC Converter Make and Type: ....
6. Schematic System Diagram *(please attach diagram)*

DESIGN ASSUMPTIONS / INFORMATION

1. Number of days autonomy used for battery sizing: .... days
   Max. battery discharge depth: .....% Max. battery cycles: ......
2. Please attach tables of monthly mean data for each month:
   (a) Irradiation in the array plane ($kWh/m^2 \cdot day$) and array tilt angle
   (b) Ambient temperature ($°C$)
   (c) Array energy output (kWh/day)
   (d) Energy to load (kWh/day)
   (e) Battery losses (kWh/day)
   (f) Power conditioning / control losses (kWh/day)
   (g) Energy used by monitoring system (kwh/day)

Contact for further information:

Name: ....
Address:

Tel: .... Fax: ... .

Completed by: .... Date: ....

* *Please complete separate sheets for each type/size used*

ANNEX F

Record Sheet for Global PV Plant Monitoring

Name of plant: .... Location: ....

Date	Time	Irradiation, Array Plane HI (Wh/m2)	and/or optionally Pot Array Energy EP (kWh)	Array Output Energy EA (kWh)	Energy to Loads EL (kWh)	Energy to Utility Grid ETU (kWh)	Energy from Utility Grid EFU (kWh)	Energy from BU-Generator EBU (kWh)	Time of Nonavailability tNAV (h)

Commission of the European Communities
Joint Research Centre — Ispra Establishment

Guidelines for the Assessment of Photovoltaic Plants

Document B

Analysis and Presentation of Monitoring Data

Issue 4.1, June 1993

PREFACE

This document describes the procedures used for the analysis and presentation of monitoring results from photovoltaic plants. The methods presented here have been developed specifically for the PV Demonstration programme managed by the Commission of the European Communities Directorate General for Energy (DG XVII) and are now used also for the monitoring of new projects under its THERMIE programme. However, their use by others is encouraged.
The relevant specifications for the actual acquisition of monitoring data are given in Document A of these Guidelines "Photovoltaic System Monitoring", which should be used along with the present text.
These documents have been prepared by the Joint Research Centre of the European Communities, Institute for Systems Engineering and Informatics (ISEI), sector ESTI (European Solar Test Installation), Ispra, Italy, with technical support from the European Working Group on PV Plant Monitoring, taking into account also recent recommendations of IEC/TC82/WG3. ESTI would welcome comments on this document and suggestions for improvements.

Contents

ANNEXES

1 INTRODUCTION

This document describes how data collected in accordance with Document A "PV System Monitoring" are analysed and presented by the Joint Research Centre of the European Communities, Ispra, Italy. It also defines the indices of performance used in the analysis.
The analysis is intended for the evaluation of data from "analytical" monitoring, in which hourly averages of the key parameters are continuously recorded, but it can readily be adapted to apply to data from "global" monitoring, in which integral values of a reduced set of data are collected at much longer intervals.
The objectives of PV Plant monitoring may be summarised as follows:

- To determine the performance, reliability and durability of the plant and its components.
- To assess the quality of the design, in particular the sizing of the array and battery and the suitability of the selected inverter(s).
- To identify the effects of poor system utilisation separately from the effects of component efficiencies and losses.
- To present the results clearly in a form that:
  - a) can be easily understood by the users and
  - b) is suitable for comparing PV installations of different sizes and different applications, operating in different climatic conditions.
- To provide users with information on the effective management and operation of their installations.
- Eventually, to provide data for a general assessment of the potential of PV technology and the improvement of system design and operation.

The analysis and methods of presentation described in this Document have been developed with these objectives in mind.

2 MONITORED AND DERIVED PARAMETERS

The parameters that should be monitored (if applicable) according to Document A are summarised in Annex A. These data represent hourly averages of instantaneous measurements, from which sums and averages over longer time intervals τ such as days, weeks, months or years can be computed. These and other derived parameters are shown in Annex B.

3 CHECKS FOR DATA CONSISTENCY AND GAPS

3.1 Procedure

All recorded data are submitted to an initial check for consistency and gaps in order to identify any obvious anomalies before any detailed analyses are carried out. Normally this initial check is carried out for each collection of data recorded on floppy disk, cartridge or tape. A reasonable range is set for each parameter recorded, based on the known characteristics of the system. Any data points which fall outside these ranges or are otherwise inconsistent with other data are ignored in the subsequent analysis.

It may become apparent after subsequent analysis that there are other errors in the recorded data which were not so obvious. Efforts are made to identify the reasons for any errors noted and steps taken to avoid similar errors occurring in future. Data should normally be accompanied by a copy of the relevant section of the operator's log book (c.f. Document A), which may help to explain any anomalies.

3.2 Presentation of checking results

These checks are used to yield the following information:

1. The **total time of monitoring activity** t_M in the reporting period τ (usually one month), i.e. the number of hours in the reporting period for which monitoring data have been recorded.
2. The **monitoring fraction** M, i.e. the ratio of total hours of monitoring activity to total hours in the reporting period $\tau : M = t_M/\tau$.
3. The **outage fraction** O, i.e. the ratio of total hours of system non-availability to the total hours in the reporting period τ: $O = \sum_\tau t_{NAV}/\tau$.
4. A chart of monitoring activity, indicating with a star (*) each hour of each day for which non-zero data have been recorded and which fall within the acceptable ranges; an example of such a chart is shown in Annex C. (Note: a star indicates that at least one non-zero data point has been recorded. It does not necessarily follow that there are sufficient other data points for that hour to justify further analysis or that the recorded values are correct, even though they fall within acceptable ranges.)
5. A chart of hours of significant irradiance and array output, indicating with a star (*) each hour of each day for which the mean irradiance in the array plane was at least 80 W/m^2 (an arbitrary value taken as a threshold) and indicating with a circle (o) each hour of each day for which the average array output power was greater than a stated minimum value (usually about 5 percent of nominal power); an example of such a chart is shown in Annex D. Different symbols ('*' and 'o') are used so that these charts can be overlaid for analysis if appropriate.
6. A list of any data points falling outside the preset ranges.

4 ENERGY BALANCES

4.1 Climatic Data

Solar radiation data for the monitoring period are presented in the plane of the PV array. Horizontal data may also be recorded to permit comparisons with conventional meteorological data from other locations, but the in-plane data are used for system performance analysis.

Irradiation values for a period τ are computed from the corresponding irradiances by integration: $\int_\tau G_I dt$. Since G_I is given in the form of hourly averages($t_r = 1$ hour), the integral can be replaced by the sum $t_r \sum_\tau G_I$. The mean daily irradiation is obtained

from this sum by dividing it by the number of hours included in the sum (τ if M is 100%, otherwise t_M) and multiplying it by 24 [h/day]: $24 \cdot t_r \sum_\tau G_I/t_M$.

4.2 Overall System Balances

In the first stage of the detailed analysis, the hourly records of the monitored data (see Annex A) are processed to determine overall energy balances for the system (see Annex E). These energy balances include energies imported from or exported to a grid connection, or from an auxiliary generator, and indicate the contribution which the PV generator has made to the overall operation of the system.

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

Total Input Energy:

$$E_{in,\tau} = E_{A,\tau} + E_{BU,\tau} + E_{FU,\tau} + E_{FS,\tau}$$

PV Array Fraction of Total Input Energy:

$$F_{A,\tau} = E_{A,\tau}/E_{in,\tau}$$

'Useful' Energy:

$$E_{use,\tau} = E_{L,\tau} + E_{TU,\tau}$$

PV array part of 'Useful' Energy:

$$E_{use,PV,\tau} = F_{A,\tau} \cdot E_{use,\tau}$$

Net Energy Drawn from the Storage System (batteries etc.):

$$E_{FS,\tau} = (E_{SO,\tau} - E_{SI,\tau})^+$$

Net Energy Supplied to the Storage System:

$$E_{TS,\tau} = (E_{SI,\tau} - E_{SO,\tau})^+$$

where x^+ denotes the positive part, i.e. $x^+ = x$ if $x > 0$, otherwise 0.
Furthermore

$$E_{A,\tau} = \int_\tau I_A \cdot V_A dt/1000$$

$$E_{BU,\tau} = E_{BU,AC,\tau} + E_{BU,DC,\tau}$$

$$E_{BU,DC,\tau} = \int_\tau I_{BU,DC} \cdot V_S dt/1000$$

$$E_{L,\tau} = E_{L,AC,\tau} + E_{L,DC,\tau}$$

$$E_{L,DC} = \int_\tau I_{L,DC} \cdot V_S dt/1000$$

while the other terms are given by integrating the corresponding power values, such as $E_{BU,AC,\tau} = \int_\tau P_{BU,AC} dt$ etc. All integrals can be replaced by sums such as $t_r \sum_\tau P_{BU,AC}$ since the recorded data of electric power parameters are hourly averages.

The mean values of these parameters over the reporting period give a good indication of the overall performance of stand-alone PV generators, hybrid PV generators and grid connected PV systems.

4.3 BOS Component Balances and Efficiencies

Energy balances over the reporting period for each of the following system components (if present) are determined by summing the energy flows into and out of the component:

- batteries
- inverters (and/or rectifiers)
- converters

These component balances may then be used to determine mean operating efficiencies (energy efficiencies) for each component (see Annex E).

5 INDICES OF PERFORMANCE

In order to be able to compare PV systems, it is important to produce normalised performance indicators. These can be obtained either by dividing the relevant energy balances by the nominal power P_o or by the total array area A_A (and total inplane irradiation). The first leads to array and final yields and the second to the overall efficiencies.

5.1 Yields (Daily Mean Values)

The following set of normalised quantities is obtained by referring all relevant energies to the nominal power P_o (in kWp) of the installation. P_o is the design value of the array output power at the maximum power point under Standard Test Conditions (STC):
The Array Yield Y_A is the daily array energy output $E_{A,day}$ per kWp of installed PV array, i.e.

$$Y_A = E_{A,day}/P_o$$

It has the dimension $kWh/(d \cdot kW_p)$ and can also be considered as the number of hours of operation per day at P_o which would give the same energy output as the recorded integral value for that day.
The Final Yield Y_f is the useful output of the PV plant per kWp installed:

$$Y_f = E_{use,PV,day}/P_o$$

The total daily in-plane irradiation $\int_{day} G_I dt$ divided by the STC reference in-plane irradiance $G_{STC} = 1[kW/m^2]$ may be used as the definition of the **reference yield**, Y_r, since, by definition of the nominal power at STC, the inplane irradiation in units of $[kWh/(m^2 \cdot d)]$ is numerically equal to a corresponding nominal array energy output in units of $[kWh/(d \cdot kWp)]$:

$$Y_r = \int_{day} G_I dt / G_{STC}$$

We can also define normalised losses as the differences between the yields, i.e.
Capture Losses by $L_c = Y_r - Y_A$ and
System Losses by $L_s = Y_A - Y_f$.
The ratio $PR = Y_f/Y_r$ is called **Performance Ratio**.
For a reporting period of n days, averages of yields and losses are obtained by summing these values over the whole period and dividing by n.

5.2 Efficiencies

The **mean array efficiency** over the reporting period τ is defined by

$$\eta_{A,\tau} = E_{A,\tau}/E_{S,A,\tau}$$

where $E_{S,A,\tau} = \int_\tau G_I \cdot A_A dt$. $\eta_{A,\tau}$ represents the mean energy conversion efficiency of the PV array, which is useful for comparison with the **nominal array efficiency** $\eta_{A,nom}$. Their difference represents diode, wiring and mismatch losses as well as energy wasted during plant operation.
The **overall PV plant efficiency** over the reporting period τ is defined as

$$\eta_{tot,\tau} = PV_{use,\tau}/E_{S,A,\tau}$$

The ratio $\eta_{tot,\tau}/\eta_{A,mean,\tau}$ is the **load efficiency**.

6 PRESENTATION OF RESULTS — GRAPHICS

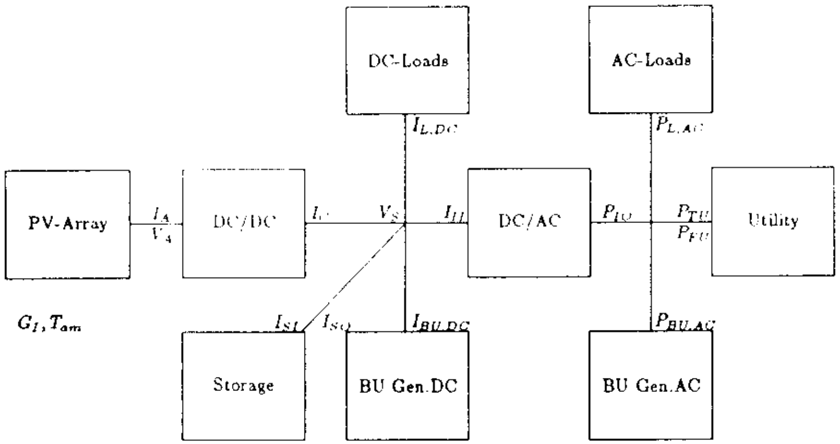
For each reporting period, in addition to a summary table containing energy balances and indices of performance, the following plots are well suited to illustrate the operation of the PV system:
a) The normalised hourly mean array output power P_A/P_o with $P_A = I_A \cdot V_A$ plotted in a scatter diagram against hourly in-plane irradiance (G_I) in $[kW/m^2]$: This graph indicates how consistently the plant operates near to its maximum capacity. It also reveals any anomalous data points, which should then be further investigated. An example of this type of graph is shown in Figure 1 of Annex F.
b) A bar graph showing daily array and reference yields (Y_A and Y_r) superimposed for each day of the month in case of monthly reports, or a bar graph showing monthly system, array and reference yields (Y_f, Y_A and Y_r) superimposed for each month in case of 6-monthly or yearly summaries. These graphs clearly show the daily capture losses in the first case or the monthly system and capture losses in the second. An example of such a plot is shown in Figure 2 of Annex F.
c) A histogram of the distribution of hourly mean In-plane Irradiance G_I, i.e. the fractional contribution of the different levels of G_I to the total in-plane irradiation: Irradiation data in this form are rather useful for design analysis. An example is shown in Figure 3 of Annex F.
d) A histogram of the normalised distribution of Useful Energy E_{use}, i.e. the fractional contribution of the different hourly mean levels of E_{use} to the total: Load data of this type may help to judge the sizing of the inverter in the case of AC systems. An example is shown in Figure 4 of Annex F.
While these plots are always included in the ESTI standard reports, other figures such as the daily or monthly input/output balances of the battery or a scatter diagram of hourly inverter output vs. inverter input should be added in cases of special interest.

Annex A — Recorded Parameters

(All data are hourly means)

PARAMETER	SYMBOL	UNIT
Irradiance, total (array plane)	G_I	W/m^2
Ambient temperature in the shade	T_{am}	$°C$
Array output voltage	V_A	V
Array output current (total)	I_A	A
Converter output current	I_C	A
Current input to storage battery	I_{SI}	A
Current output from storage battery	I_{SO}	A
dc line voltage (battery voltage)	V_S	V
Current to all dedicated dc loads	$I_{L,DC}$	A
Inverter/rectifier dc current (+/-)	I_{II}	A
Inverter/rectifier ac power (+/-)	P_{IO}	kW
Power to all dedicated ac loads	$P_{L,AC}$	kW
Power to the utility grid	P_{TU}	kW
Power from the utility grid	P_{FU}	kW
Power from auxiliary ac generator	$P_{BU,AC}$	kW
Current from auxiliary dc generator	$I_{BU,DC}$	A
Non-availability to load	t_{NAV}	hr

POWER FLOW DIAGRAM



Annex B — Summary of Definitions

In the following table all time integrals can be computed by summing hourly mean values of the recorded quantities for all hours contained in the reference period τ (such as 'day', 'month', ...). Whenever necessary, the reference period may be indicated by a corresponding subscript. In general, however, it is implied and not explicitly written.

Meteorology

G_{STC} = STC Reference Inplane Irradiance = $1[kW/m^2]$
STC = Standard Test Conditions:
- inplane irradiance equal to G_{STC}
- total solar AM1.5 spectral irradiance distribution in accordance with IEC904-3
- uniform array temperature of $T_{STC} = 25°C$.

$E_{S,A}$ = Total solar energy on array plane $[kWh]$: $\int_\tau G_I \cdot A_A dt$

Photovoltaic Array

P_o = Nominal Power $[kWp]$:
Design value of the PV array output at the maximum power point under STC
A_A = Array Area: (Module area)*(Number of modules in the array) $[m^2]$
E_A = Array output energy $[kWh]$: $\int_\tau I_A \cdot V_A dt/1000$
$\eta_{A,nom}$ = Nominal Array Efficiency: $P_o/(A_A \cdot G_{STC})$
$\eta_{A,mean}$ = Mean Array Efficiency: $E_{A,\tau}/E_{S,A,\tau}$

Storage

E_{SI} = Energy supplied to storage $[kWh]$: $\int_\tau I_{SI} \cdot V_S dt/1000$
E_{SO} = Energy drawn from storage $[kWh]$: $\int_\tau I_{SO} \cdot V_S dt/1000$
E_{TS} = Net energy supplied to storage $[kWh]$: $(E_{SI} - E_{SO})^+$
E_{FS} = Net energy drawn from storage $[kWh]$: $(E_{SO} - E_{SI})^+$
ρ_Q = Coulomb Recharge Fraction of the storage battery: $\int_\tau I_{SI} dt / \int_\tau I_{SO} dt$
ρ_E = Energy Recharge Fraction of the storage battery $E_{SI,\tau}/E_{SO,\tau}$

Power Conditioner

E_C = Output energy from DC/DC converter $[kWh]$: $\int_\tau I_C \cdot V_S dt/1000$
η_C = Converter Efficiency: $E_{C,\tau}/E_{A,\tau}$
E_{II} = dc-energy input to inverter $[kWh]$: $\int_\tau I_{II} \cdot V_S dt/1000$
E_{IO} = ac-energy output from inverter $[kWh]$: $\int_\tau P_{IO} dt$
η_I = Energy Efficiency of the inverter: $E_{IO,\tau}/E_{II,\tau}$

Load

E_L = Energy to loads $[kWh]$: $E_{L,AC} + E_{L,DC}$
$E_{L,AC}$ = Energy to ac loads $[kWh]$: $\int_\tau P_{L,AC} dt$
$E_{L,DC}$ = Energy to dc loads $[kWh]$: $\int_\tau I_{L,DC} \cdot V_S dt/1000$

Utility Grid

E_{TU} = Net energy supplied to utility grid $[kWh]$: $\int_\tau P_{TU} dt$
E_{FU} = Net energy drawn from utility grid $[kWh]$: $\int_\tau P_{FU} dt$

Back-up Sources

E_{BU} = Energy from Back-Up system $[kWh]$: $E_{BU,AC} + E_{BU,DC}$
$E_{BU,AC}$ = Energy from ac BU generator $[kWh]$: $\int_\tau P_{BU,AC} dt$
$E_{BU,DC}$ = Energy from dc BU generator $[kWh]$: $\int_\tau I_{BU,DC} \cdot V_S dt/1000$

Monitoring System

t_M = total time in the reference period for which monitoring data are recorded [h]
M = Monitoring Fraction: t_M/τ

System Energies

E_{in}	=	Total (electrical) Input Energy $[kWh]$
	=	$E_A + E_{BU} + E_{FU} + E_{FS}$
F_A	=	PV Array Fraction of total input energy: E_A/E_{in}
E_{use}	=	Useful Energy supplied by the system $[kWh]$
	=	$E_L + E_{TU}$
$E_{use,PV}$	=	Direct PV energy contribution to E_{use} $[kWh]$: $F_A \cdot E_{use}$

System Performance Indices

O	=	Outage fraction: $\sum_\tau t_{NAV}/\tau$
Y_r	=	Reference Yield = $\int_{day} G_I dt/G_{STC}$ $[kWh/(d \cdot kWp)]$
Y_A	=	Array Yield = $E_{A,day}/P_o$ $[kWh/(d \cdot kWp)]$
Y_f	=	Final Yield = $E_{use,PV,day}/P_o$ $[kWh/(d \cdot kWp)]$
L_c	=	Capture Losses $= Y_r - Y_A$ $[kWh/(d \cdot kWp)]$
L_s	=	System Losses = $Y_A - Y_f$ $[kWh/(d \cdot kWp)]$
PR	=	Performance ratio: Y_f/Y_r
η_{tot}	=	Overall PV plant Efficiency: $E_{use,PV,\tau}/E_{S,A,\tau}$

Annex C --- Chart of Monitoring Activity

```
Contract: SE/nnn/yy                 Site: xxxxxxxxxx

PERIOD: 1.-30. 4.1990


        HOURS OF MONITORING ACTIVITY PER DAY OF MONTH


        day ('*' means monitoring activity at that hour)

                      noon
             ...........|............
        ___
          1   ***********************
          2  ************      ******
          3  ************************
          4  *******  ***************
          5  ************************
          6  ************************
          7  *******************   **
          8  ************* **********
          9  ************************
         10  ************************
         11  ************************
         12  ************************
         13  ************************
         14  ************************
         15  ************************
         16  *********** ************
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         23  ************************
         24  ************************
         25  ************************
         26  ************************
         27  ************************
         28  ************************
         29  **************
         30

             ...........|............
                      noon
```

Annex D

Chart of Hours of Significant Irradiance and Array Output

Contract: SE/nnn/yy   Site: xxxxxxxxx

Nominal Power P_o: 3.80 [kW_p]   Total Array Area A_A: 48.50 [sqm]

PERIOD: 1.-30. 4.1990

```
            HOURS OF IRRADIANCE           HOURS OF ARRAY OUTPUT
            exceeding 80 W/m2             exceeding 0.05Pnom

day               noon                          noon
       .............|.............   ............|.............
____
  1            **********                       ooooooooo
  2           ***      **                    ooo       oo
  3             ******                          oooooo
  4            *********                        oooooooo
  5            *******                        ooooooooo
  6            *********                      ooooooooo
  7                                               o
  8              *                                o
  9             **                              oooooo
 10             ***********                   oooooooooo
 11                ******                         oooooo
 12            ******** *                     ooooooooo
 13            *********                      ooooooooo
 14              *********                      ooooooooo
 15             *   ******                      ooooo ooo
 16           ** ********                     o oooooooo
 17           **********                     oooo ooooo
 18            *********                      ooooooooo
 19            ****** ***                     oooooo ooo
 20           ***********                    ooooooooooo
 21            ****** ***                     oooooooooo
 22           ***** ******                   ooooo oooooo
 23                ****                           oooo
 24            **********                     oooooooooo
 25           ******** *                     oooooooo o
 26           ***********                    ooooooooooo
 27             *****                           ooooo
 28           ************                    ooooooooooo
 29            ****                             ooo
 30
       .............|.............   ............|.............
                  noon                          noon
```

Annex E --- Energy Balances

Contract: SE/nnn/yy   Site: xxxxxxxxxxxx   PERIOD: 1.-30. 4.1990

Nominal Power P_o: 3.8[kW_p]   Total Array Area A_A: 48.50[m^2]

Total time of monitoring h_M [hrs]= 671   Monitoring Fraction M = 0.932

Outage Fraction O = 0

CLIMATIC DATA

Recorded total solar energy in array plane $E_{S,A}$: 3393.4 kWh

Monthly mean daily irradiation in array plane: 2.50 kWh/(m^2d)

SYSTEM BALANCES

Total array output energy E_A(kWh): 185.3

Energy supplied to utility grid E_{TU}(kWh): 0.0

Energy drawn from utility grid E_{FU}(kWh): 0.0

Energy from back-up generator E_{BU}(kWh): 43.6

Total energy (kWh) to
DC loads $E_{L,DC}$: 0.0   AC loads $E_{L,AC}$: 163.2

Total Input Energy E_{in}(kWh) = 228.9   PV Fraction F_A = 0.81

Useful Energy E_{use}(kWh): 163.2 $E_{use,PV}$ (kWh): 132.1

BOS COMPONENT BALANCES AND EFFICIENCIES

Converter Efficiency n_C: 0.910

Energy (kWh) to batteries E_{BI}: 111.8,   from batteries E_{BO}: 93.0
Energy Recharge Fraction p_E: 1.20

Energy (kWh) to inverters E_{II}: 180.2,   from inverters E_{IO}: 163.2
Energy Efficiency of inverter n_I: 0.89

INDICES OF PERFORMANCE

Yields kWh/(kW_pd):
Reference Y_r: 2.50   Array Y_A: 1.74   Final Y_f: 1.24

Mean array efficiency n_A: 0.055
Overall plant efficiency n_{tot}: 0.039

Performance Ratio PR: 0.50

ANNEX F --- GRAPHICS

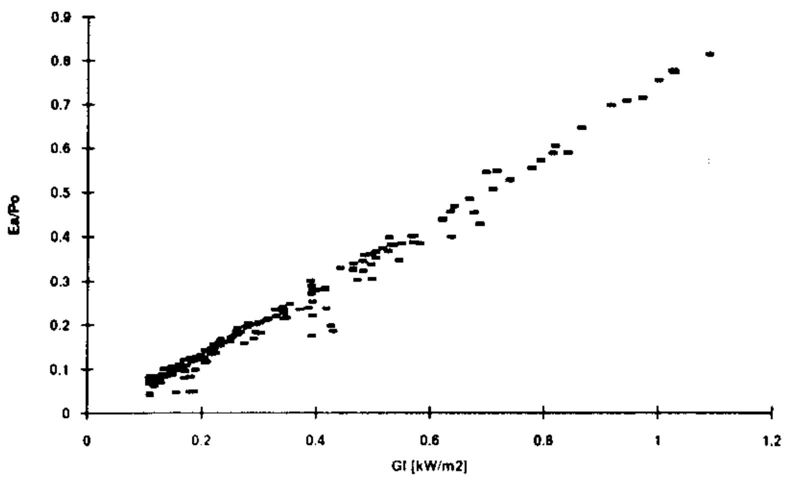

Fig. 1: Scatter Diagram of Hourly Mean Array Power vs. Hourly Mean Irradiance

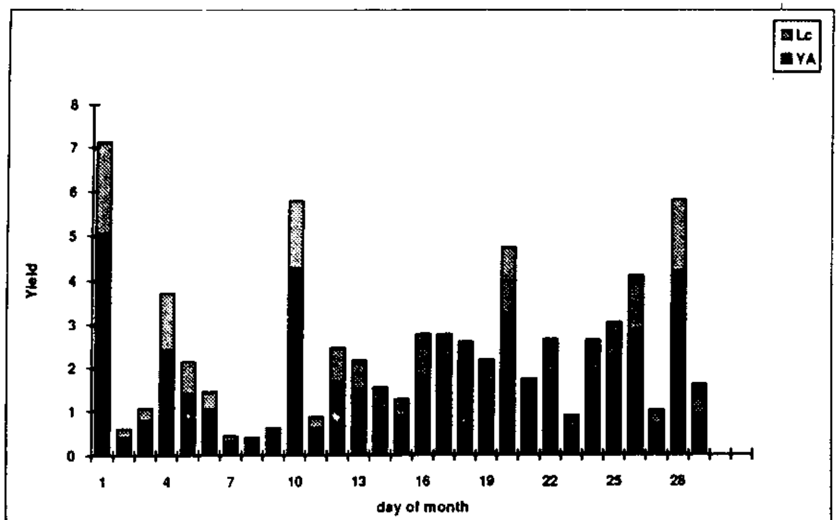

Fig.2: Daily Arrays Yields (Y_A) and Capture Losses(L_c) [kWh/(d*kW_p)]

ANNEX F --- GRAPHICS (continued)

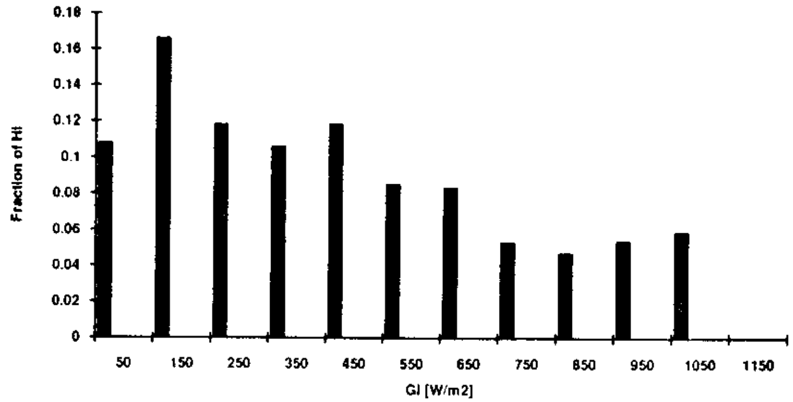

Fig. 3: Histogram of Normalised Distribution of In-plane Irradiance

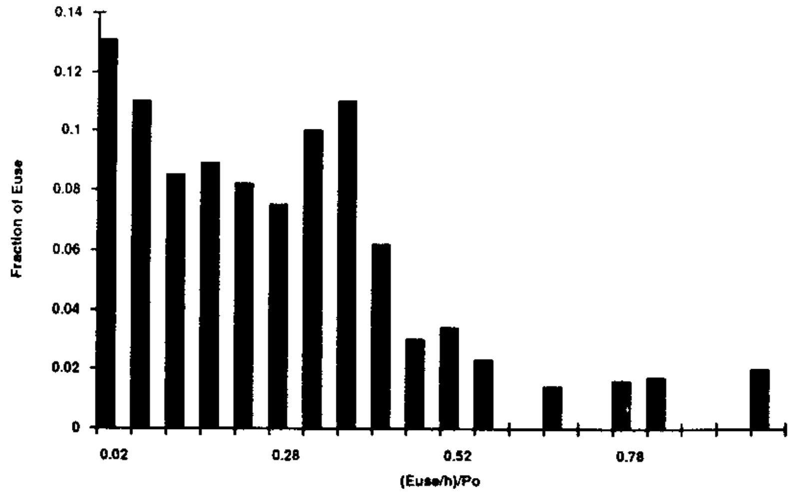

Fig.4: Histogramm of Normalised Distribution of 'Useful Energy'