PV Energy Supply of a Danish Standard House Experiments on Battery Storage

Final report

February 1990

Contents

1. Summary

This PV-project is based on 2 EC contracts i.e.:

The EC contract No. ESC-R-097-DK (signed 1984) with the title "Photovoltaic Solar Energy Supply for a Danish Standard House" and EC contract No. EN 3 S-0211-08 (SP) (signed 1989) with the title "PV Energy Supply of a Danish Standard House; Experiments on Battery Storage"

Contract No. ESC-R-097-DK includes a photovoltaic energy supply system for a specially designed Danish standard house intended for export, developed and put into operation in 1984. The house is especially adapted for PV powering, and great importance has been attached to fitting the PV-arrays into the roof in the best possible way from an architectural point of view.

AEG polycrystalline solar cells with a maximum power of 5.01 kW have been installed.
The power conversion equipment is constructed as 20 kHZ switch-mode and produces 10 kW at 220 V ac 50 Hz.

The antimony-free batteries have a maximum capacity of 200 Ah(10) each and are constructed as two parallel batteries of 108 cells.

The highly advanced computer equipment carries out the general control and supervision of the entire PV-system and data storage.
E.g. the cell voltage of the battery and the state of charge of the battery are recorded continuously.

The plant phase belonging to this contract is thoroughly described in the final report of October 1984 and therefore not described in details in this report.

Under the EC-contract No. EN-3S-0211-08 (SP) the work programme includes i.a. the carrying out of battery experiments, component evaluation, analyses of operational data and report of the entire operational period from July 1, 1984 to July 1, 1989.
Thus, this report describes these subjects in detail and the entire operational period of the project.

2. Introduction

The EC-Commission has made a marketing study concerning the possibilities of photovoltaic (PV) energy supply of single houses.

The result was that a real market in the commercial sense exists, i.a. in the Mediterranean area when houses far from the public mains connection are considered.

With a view to examining the interest in a possible Danish PV-house project an application was made - via the Danish Department of Energy - to Jutland Telephone being the only company in Denmark which has carried on long-term experiments with major PV-plants.

An application from Jutland Telephone to various Danish industries resulted in a co-operation concerning the above-mentioned project with Jutland Telephone as contractor to the EC.

The project "Photovoltaic Solar Energy for a Danish Standard House" was started in February 1984 under contract No. ESC-R-097 DK and with Jutland Telephone as the contractor. The house and PV-plant was planned and established in Denmark in approx. 5 months and was put into operation on July 1, 1984. The description of plant and planning etc. is included in the final report of the contract of October 1984.
According to the above-mentioned contract, the operational period totals 5 years from July 1, 1984 to July 1, 1989.

A new contract, No. ENS-0211-DK(SP) with the title "PV Energy Supply of a Danish Standard House; experiments on battery storage" was signed on February 14, 1989.

The period of the new contract is 11 months from 01.02.1989 and concerns i.a. the preparation of the final report for the five-year operational period from July 1, 1984 to July 1, 1989.

This report includes i.a. a brief plant description, a component evaluation, and a description of the operational period from July 1, 1984 to July 1, 1989 and special importance has been attached to the battery analysis.

As regards further details concerning the establishment phase of the project, please see final report of October 1984.

3. Project organization

In order to carry out the project Jutland Telephone established a co-operation with 3 Danish companies:

Contractor:

Jutland Telephone	Jutland Telephone T-Power Supply Section Sletvej 30 DK-8310 Aarhus-Tranbjerg J Phone +45 86 29 33 66

Sub-contractors:

Lyac Power A/S	Accumulatorfabrikken LYAC Lyacvej 16 DK-2800 Lyngby
Alex Grosman A/S	Alex Grosman Transformervej 13 DK-2730 Herlev
Kalmargården A/S	Kalmargården Hellesvej DK-6740 Bramming

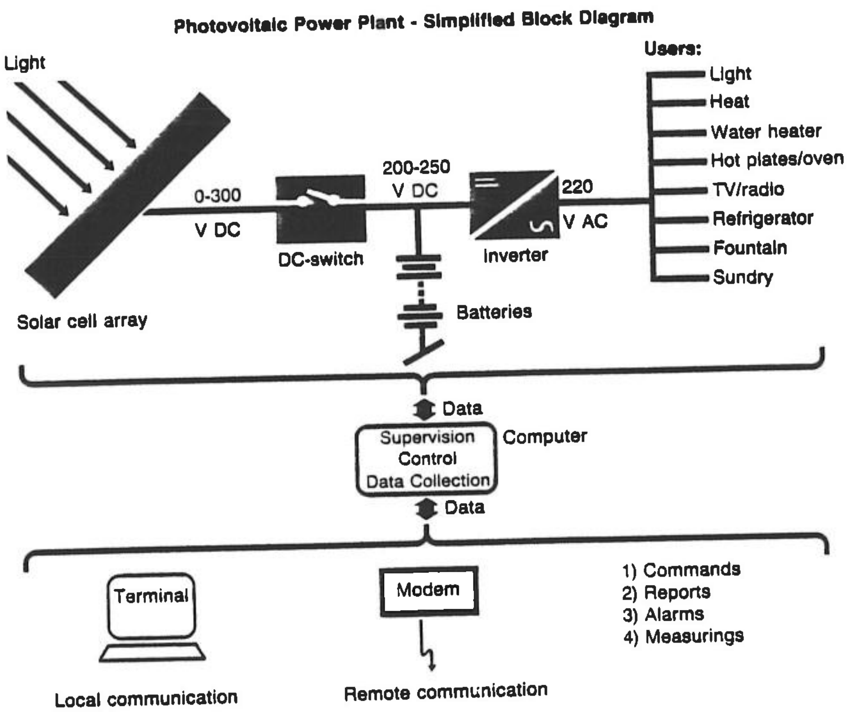
4. Plant description

The objective of the project is to supply a Danish standard house with energy from a PV-plant mounted on the roof.

4.1. Main principle

The plant has been built up at block diagram level as shown on the outline below:

Fig. 4.1. a: Simplified diagram



4.2. Function of the system

At the roof of the house a number of solar cell arrays has been mounted corresponding to a maximum output of approx. 5 kW (AM1, 25°C).

These arrays are divided into nine parallel strings each supplying a voltage of 0-300 V dc. The voltage depends on load and solar intensity.

To be able to maintain an appropriate level of the battery voltage the individual strings are connected or disconnected by means of remotely controlled dc-switches. See page 8

The energy production from the solar cell arrays is kept in a battery storage if it is not directly used.

If the battery storage is fully charged strings will be connected or disconnected until accordance between load and output from the PV-arrays is obtained.

By measuring the production from the strings still connected, the output which might have been supplied by the disconnected strings is calculated.
Together with the other data from the plant this figure is stored on the disc under the designation "PV-surplus".

The dc output of the battery is converted into a single-phase ac voltage output by the inverter. The output is in accordance with the customers' requirements as to quality and quantity.

The ac power is distributed in a group panel to the low voltage installation of the house. The supervision unit (DRO-4) is able to connect or disconnect the individual groups for simulation of a normal family consumption day and night.

For supervision and control of the entire plant a micro processor based supervision unit DRO-4 is mounted. The DRO-4 supervises and controls all components forming part of the plant.

Besides real-time supervision of the plant, the DRO-4 is able to collect and store data of all the measured values.
As DRO-4 has been equipped with a modem, connection to the plant can be established via this modem by means of an ordinary telephone connection.

To observe the operation of the plant locally, a terminal is mounted in direct connection with the DRO-4.

Owing to the security of the battery a mains connected rectifier has been mounted to maintain a minimum level of the capacity.

4. Discription of main coponents.

4.3.1. The house

The house, constituting the physical frames of the pilot plant, is especially designed for this purpose.

In connection with the design and arrangement of the house importance has been attached to the fact that this house is to function as an ordinary single-family standard house.
Besides the size and construction of the roof surface no special considerations have been taken which makes it deviate from a standard house.

At the arrangement great importance has been attached to the fact that the technique room should be placed as remotely as possible and take up little room.

Fig. 4.3.1.a: Drawing of house:

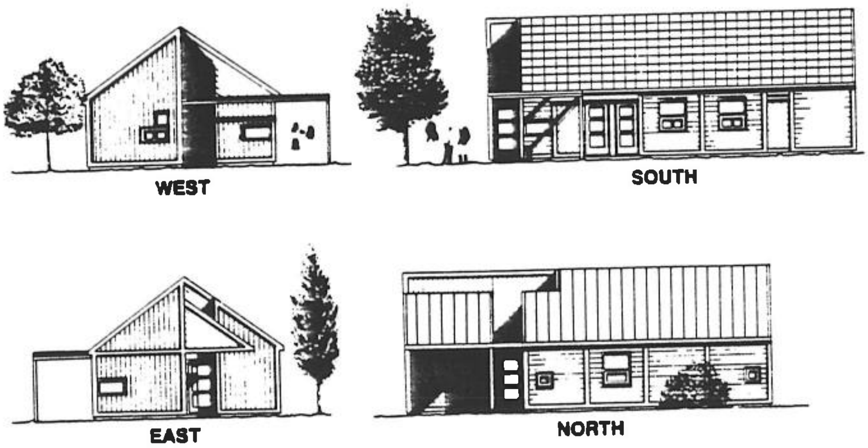
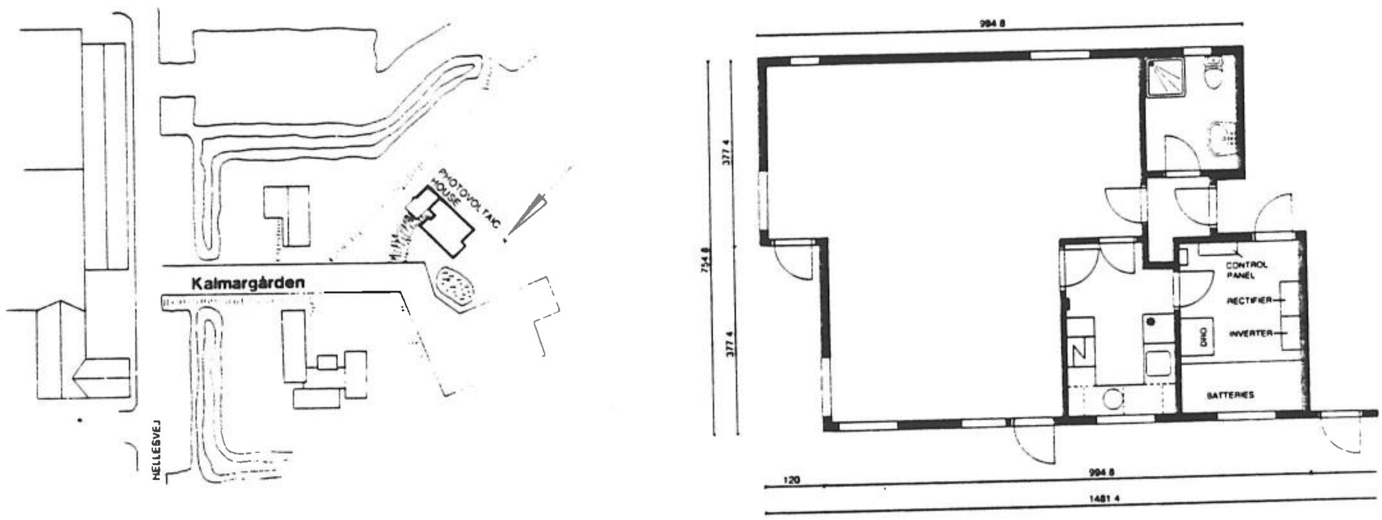


Fig. 4.3.1.b: Arrangement and placing of the house.

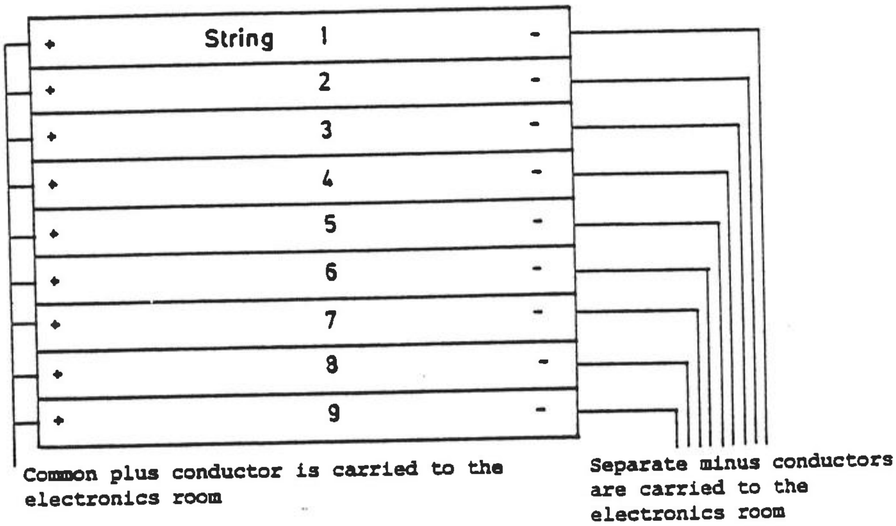


Electrically the house has been equipped with all the installations which are normal in a single-family house. All electrical appliances are single-phased and by means of contactors they can be remotely controlled for connection or disconnection.

4.3.2 PV-system

The PV-system has been built up as shown on the outline below:

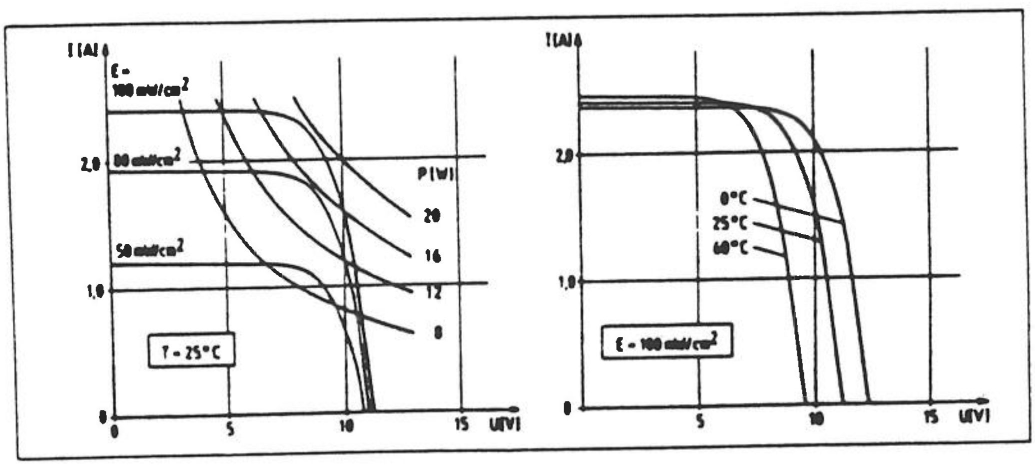
Fig. 4.3.2.a: Electric configuration



The modules are delivered by AEG-Telefunken and are of the type PQ10/20/0. Each module has the specifications shown below.

Fig. 4.3.2.b: Electric data for arrays

Current/Voltage Characteristic



Electrical Data

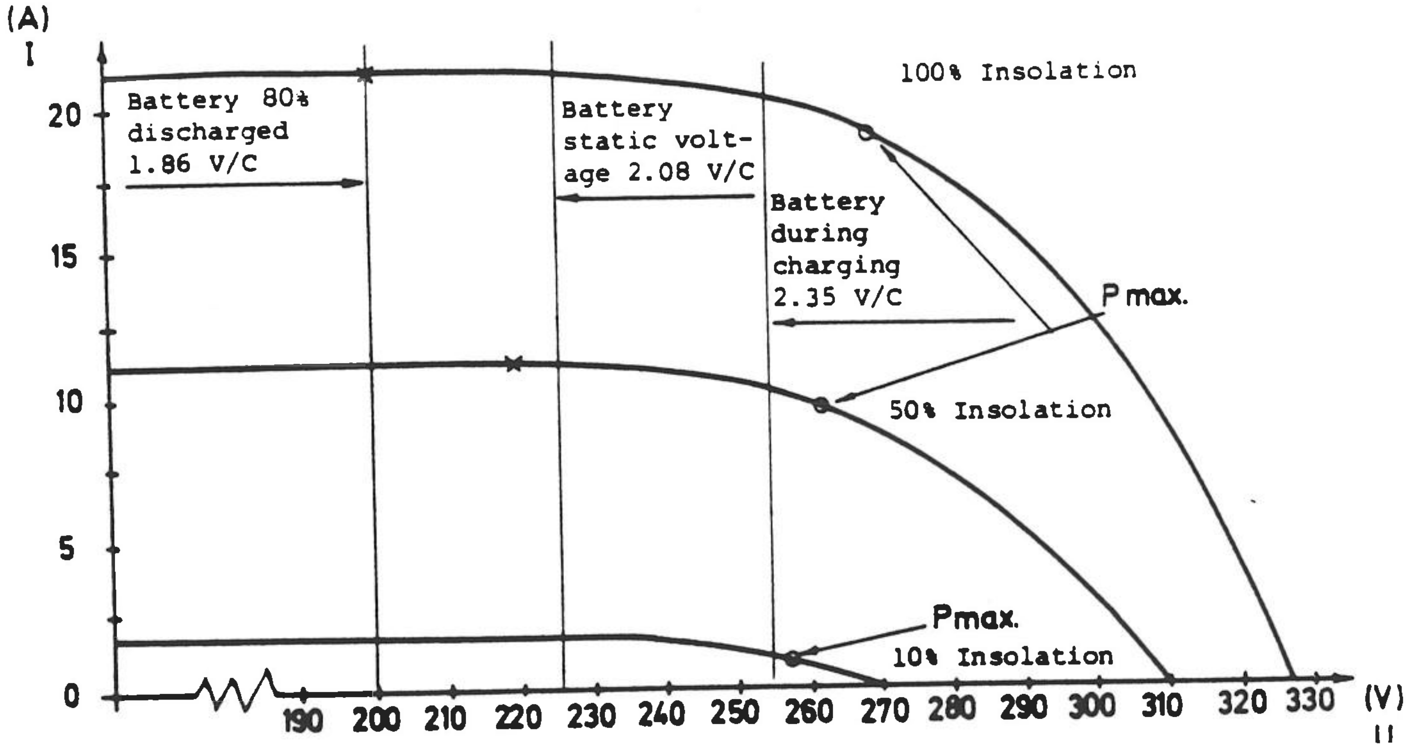
Electrical data as a function of the operating temperature

Characteristic values (AM1 – 100 mW/cm²)	Operating temperature 0 °C	25 °C	60 °C
Open-circuit voltage (V)	12.3	11.2	9.6
Short circuit current (A)	2.37	2.41	2.46
Current at maximum power (A)	2.18	2.20	2.23
Max. Power (W)	21.3	19.2	16.2

The system consists of 9 parallel strings each consisting of 29 modules.

This number has been chosen in order to have the maximum power at a voltage which is as close to nominal charge voltage for the battery as possible without using MPPT-equipment. (Maximum Power Point Tracking).

Fig. 4.3.2.c: Characteristics of a PV-array at 25°C.



4.3.3. Rectifier and inverter

4.3.3.1. Rectifier:

As previously mentioned a rectifier was installed in order to maintain a minimum capacity of the battery. The rectifier is a traditional thyristor regulated type which is not to be considered as an actual part of the system.
The rectifier is directly connected to the mains and can supply 20A at 240V.
The energy which is supplied from the mains when charging the battery is registered and stored together with the other data of the plant.

4.3.3.2. Inverter

In connection with the establishment phase one of the part objectives was to develop and produce an inverter suitable for application in this system and the requirements were the following:

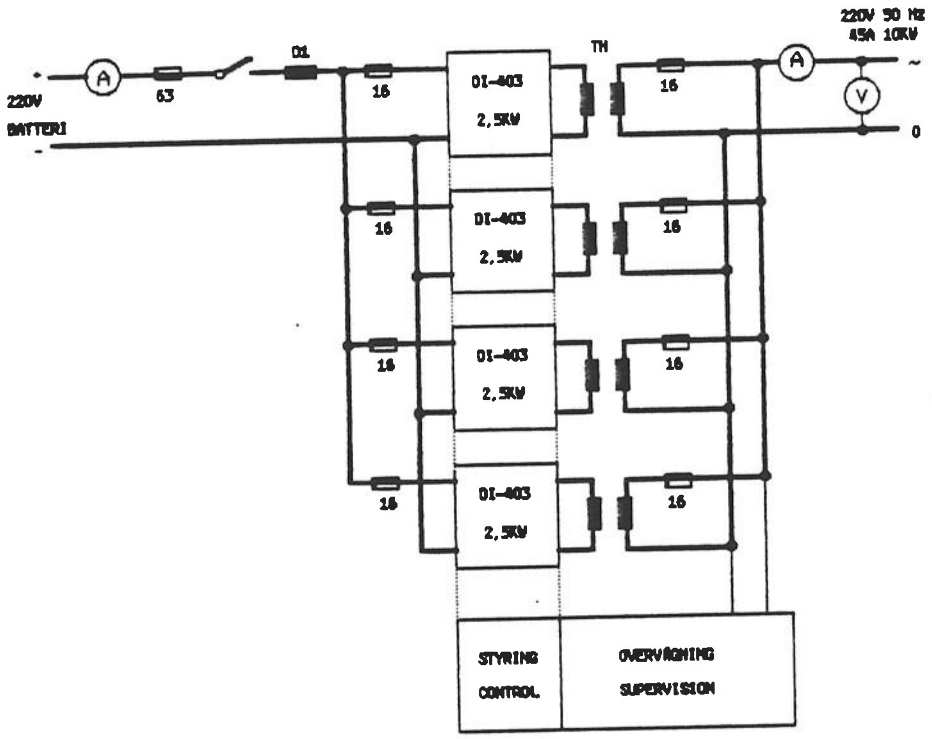
- output power 10kW
- input voltage between 200-260V
- output voltage 1* 220V, 50 Hz
- built up of modules
- high efficiency
- switch-mode

The inverter, developed by the firm of Alex Grosman, is based on PWM system with a switching frequency of 20/40 kHz.
In order to supply the required 10 kW the inverter has been built up of 32 power modules each containing a semi bridge connection.

The PWM system is built up with power mosfet transistors and besides a non-audible operation this results in a minor need for power for the control modules.

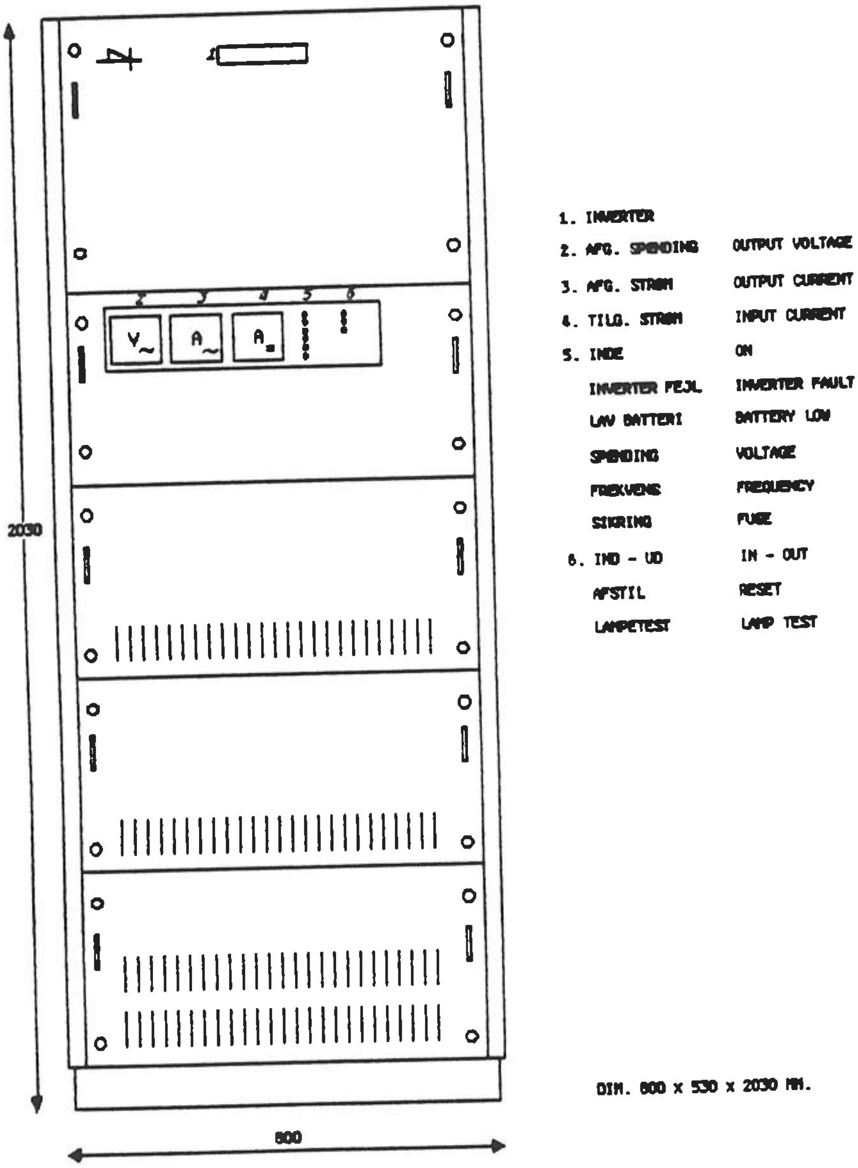
The 32 power modules are divided into 4 groups each with 8 power modules of 625 W. Each of the four groups is connected to its own transformer. The secondary sides of the transformers have then been parallelly connected to give a total power of 10 kW.

Fig. 4.3.3.2.a: Electrical configuration of the inverter.



The inverter rack is built up in iron plate and the four transformers are placed at the bottom of the inverter. Four rows each consisting of 8 power modules are placed in slide bars and connected via multi-plugs which result in easy servicing and construction.

Fig. 4.3.3.2.b: The mechanic structure of the inverter



The supervison and control units for the operation of the inverter are placed above the power modules. For control of the frequency of the inverter a crystal controlled frequency generator has been applied.
Thus, the supervision has been divided so that the four groups are supervised individually and by means of light-emitting diodes it is possible to localize a defective power module.

In connection with excess of adjustable tolerances of frequency and voltage the inverter will disconnect the load.

The PMW inverter can be loaded continuously by 10 kW. In connection with overload of up to 160%, the inverter maintains frequency and voltage for approx. 2 secs whereafter the power modules disconnect.
Restart of the inverter can take place manually or by means of remote control via the microprocessor supervision.

With an overload degree of 160% for 2 secs it is possible to manage start of e.g. refrigerator etc. even though the inverter already is fully loaded.

The structure of the distribution for allocation of the output will appear from later descriptions.

4.3.4. Battery storage

The battery storage consists of two batteries of 200 Ah(10) each, connected in parallel.

The size of the batteries has to be seen in relation to where the batteries are to be placed. The chosen size of battery and the expected load of 12 kWh on an average per 24 hours at the time it was put into operation should permit operation for approx. 6 days without supply from the PV-plant if the discharge is 80%.

The battery is of the type GRL which indicates that it is an antimony-free battery. Each battery consists of 36 blocks each having 3 cells built together.
The battery is manufactured and delivered by the firm of Lyac Power A/S.

The supplier states the following specifications:

Water filling interval 3 years

Self-discharge:	Less than 0.1% per 24 hours of 10-kap at 30°C
Temperature range:	5-35°C
Positive plates:	Tubular plates of special alloy
Negative plates:	Lubricated grid plates with Lyac's special pasta
Battery boxes:	Styrene acrylic nitrite (SAN)
Separators:	Microporous plastic separators. Electric resistance less than 0.2 microohm/cm^2
Electrolyte:	Sulphuric acid
Charging:	Maintenance voltage 2.22-2.24 V/cell Charging voltage in PV-plant less than 2.35 V No requirements to current limitation if the charging voltage is 2.35 V/c or less

4.3.5. Microprocessor supervision DRO-4

The supervision and control equipment for this project is based on DRO-1, developed by Jutland Telephone, and intended for supervision of telepone exchanges' power supply plants.

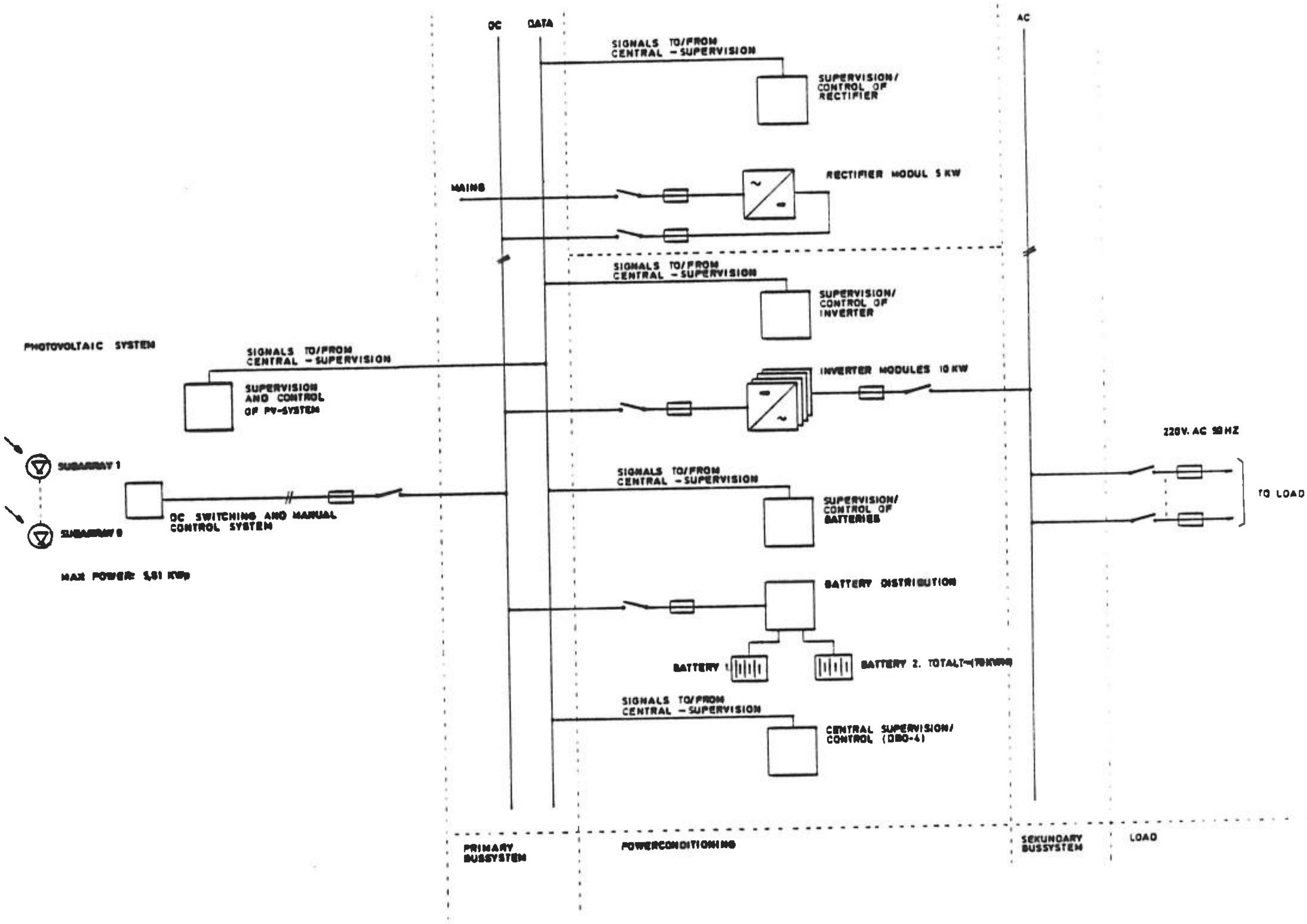
The further development of the DRO-1 which resulted in the DRO-4 has been carried out during the project and this DRO-4 has the following main functions:

1. Supervision and control of the PV-installation.
2. Supervision of battery storage.
3. Dc and ac voltage supervision.
4. Measuring functions for battery capacity.
5. Supervision and control of the load.
6. Power-flow control.
7. Alarm supervision and communication.
8. Data registration and collection.

Technical data:

- 128 analog inputs
- 32 digital inputs
- 32 digital outputs
- 40 kb RAM
- 24 kb PROM
- 2 floppy discs of 800 kb each
- 16 bits/12 Mhz processor

Fig. 4.3.5.a: Key diagram of the entire plant



4.3.5.1 Supervision and control of the PV-installation

As previously mentioned the photovoltaic plant consists of 9 parallel strings each consisting of 29 PV modules.

The output current of each string is measured every 60 secs and compared with the voltage and then the output is calculated. The individual output power from each string is compared and if deviations in the output occur from a single string compared to the average of the others, an alarm is given.

In case of a minor sun irradiation this alarm is blocked, as the calculations in connection with the PV-production is too dubious.

In this way it is possible to supervise the strings without considering the external influences like temperature, dust on the arrays, age, etc.
Short deviations possibly owing to partial shade effects will not cause an alarm.

Connection and disconnection of the individual strings are controlled by the computer due to the battery voltage occuring at any time. By controlling the PV-arrays on the voltage it is possible to be within the acceptable range for the battery voltage and simulataneously utilize the PV-array as close to the maximum point of their power as possible.

4.3.5.2. Supervision of battery storage

The DRO measures each block voltage in the battery and thus it is possible quickly to find irregularities in the battery before this influences the ability of the battery to function as operational reserve for the entire installation.

On the basis of the individual block voltages the mean value is calculated and compared to the individual block voltage. An alarm is given in case of an excess of a further fixed tolerance.

When using this dynamic measuring method the result is independent of the total voltage on the battery and of the condition of battery capacity. In connection with charging on the battery the tolerances of the block voltage spreadings will increase automatically.

If the block voltages or the total voltage exceed a further fixed maximum or minimum value an alarm is given immediately.

By means of a thermister the temperature of the electrolyte is measured in one or more blocks. The thermistor is enclosed in acid firm material and is mounted with a bayonet socket in the normal filling hole of the battery. An alarm is given if the temperature exceeds a further fixed range.

The electrolyte level in the battery is measured with a unit converting the level into a signal which in the DRO is converted into a percentage of the actual battery's max./min. level. An alarm is given in case of excess of a further fixed level.
Just like the temperature measuring device this unit is mounted with a bayonet socket in the water filling hole of the battery.

All the above measurements can be printed out in various reports via remote communication. Furthermore, it is possible to change all alarm limits as well as reset the alarms via remote communication.

4.3.5.3. Dc/ac voltage supervision

The DRO-4 contains a number of dc measuring channels for measurement of battery voltages, auxiliary voltages, etc.

The measuring principle is the same as for the block voltage measurings. By excess of fixed limits an alarm is given indicating the channel in question.
All limits can be changed via the communication interface.

Supervision of inverter voltage and frequency is based on the internal supervision of the inverter and in connection with alarm from here this alarm is sent via the communication.

4.3.5.4. Capacity measuring function

It is well-known that it is difficult to find the actual capacity of a lead acid battery without making an actual discharge test.
Normally it will be possible to have an indication of the capacity content by carrying out a specific density measurement. But owing to the acid stratification which is pronounced in case of low-antimony batteries this method is not applicable for precise measurements.
Furthermore, it is not possible to make specific gravity measurements electronically with the equipment existing at the moment.

Because of the above the DRO has been developed to handle this function.
By carrying out measurements continuously of the current to and from the battery (every 10 secs) and comparing these measurements with known data for the actual battery, the DRO is able to calculate, by means of advanced algorithms, the actual capacity of the battery.

When the temperature of the battery is known it is possible to make corrections for either an increase or decrease of the calculated capacity of the battery as a result of this temperature.

In connection with this project a rectifier has been mounted to maintain a minimum level of the battery capacity and it is thus possible for the DRO to initiate a charging progress to secure that the battery in case of an inadmissible low capacity level is charged to 100%.

4.3.5.5. Supervision and control of load

The load in the house has been divided into various groups as in any normal installation.

There are 9 different consumer groups in the installation. Each of these groups can be connected or disconnected individually by the DRO at random chosen time intervals. Furthermore, programming of these time intervals can take place via the communication interface.

Fig. 4.3.5.5.a: Outline from DRO of timer adjustments.

DATE: 891011 HOUR: 1409

TIMER	ACTIVE	START	RUN-TIME	INTV. (DAYS)
1		07:00	04:00	1
		15:00	07:00	1
2		07:00	04:00	1
		15:00	07:00	1
3	X	00:01	23:59	1
4	X	00:01	23:59	1
5	X	00:01	23:59	1
6	X	00:01	23:59	1
7	X	07:00	12:00	1
8				
9	X	00:01	23:59	1

When the house was put into operation the division of load was as follows:

- 3 various electric lighting groups
- 3 kitchen groups
- 3 heating groups

By connection and disconnection of these loads and by using the house as meeting and working room the average load can be controlled in this way to be approx. 12 kWh/24 hours.

When the house has been used for meeting activity and the time for these meetings was not in accordance with the pre-programmed times for connection of the electric lighting groups it is possible to connect all groups for a period of 3 hours at a time on a special supervison panel in the kitchen.

4.3.5.6. Power-flow control

As previously mentioned the DRO-4 controls the production from the PV-arrays by connecting and disconnecting the strings.

This form of control, based on the battery voltage will in case of a fully charged battery adjust the number of strings which are to be connected, to correspond to the actual load.

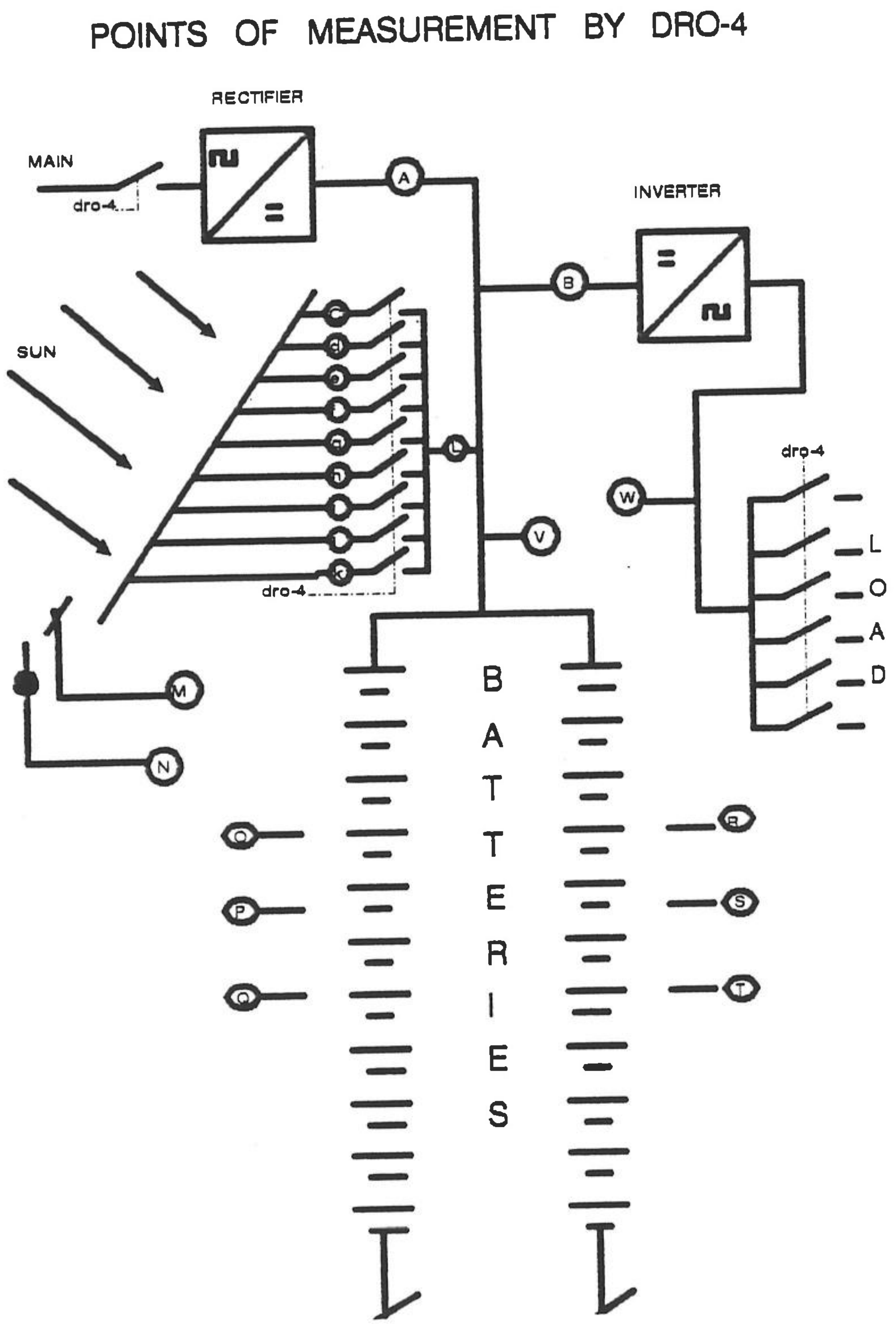
If the battery is not fully charged, the DRO will connect the number of strings necessary to maintain a suitable battery voltage. Besides, this voltage is adjusted so that the array load is very close to the optimum power level.
As the load on the plant is larger than what can be expected from a PV-array of this size placed in Denmark, a rectifier has been mounted.

The rectifier which is connected to the mains is controlled to start/stop by the DRO-4 dependent on the capacity level of the battery.
The energy from the mains to this rectifier is carefully registered by DRO-4 and stored.

See the test point diagram overleaf where the following points are measured:

A: Rectifier current is measured every 10 secs.
B: Current to inverter is measured every 10 secs.
C: Current from PV-string 1 is measured every minute.
D: Current from PV-string 2 is measured every minute.
E: Current from PV-string 3 is measured every minute.
F: Current from PV-string 4 is measured every minute.
G: Current from PV-string 5 is measured every minute.
H: Current from PV-string 6 is measured every minute.
I: Current from PV-string 7 is measured every minute.
J: Current from PV-string 8 is measured every minute.
K: Current from PV-string 9 is measured every minute.
L: Current from entire array is measured every minute.
M: Irradiance is measured every minute.
N: Outdoor temperature and PV-temperature every minute.
O: Temperature of battery 1 electrolyte.
R: Temperature of battery 2 electrolyte.
P: Electrolyte level in battery 1.
S: Electrolyte level in battery 2.
Q: Block voltages on 36 blocks in battery 1.
T: Block voltages on 36 blocks in battery 2.
V: Dc bus voltage is measured every minute.
W: The inverter's voltages and currents are measured.

Fig: 4.5.3.6.a: Test point diagram

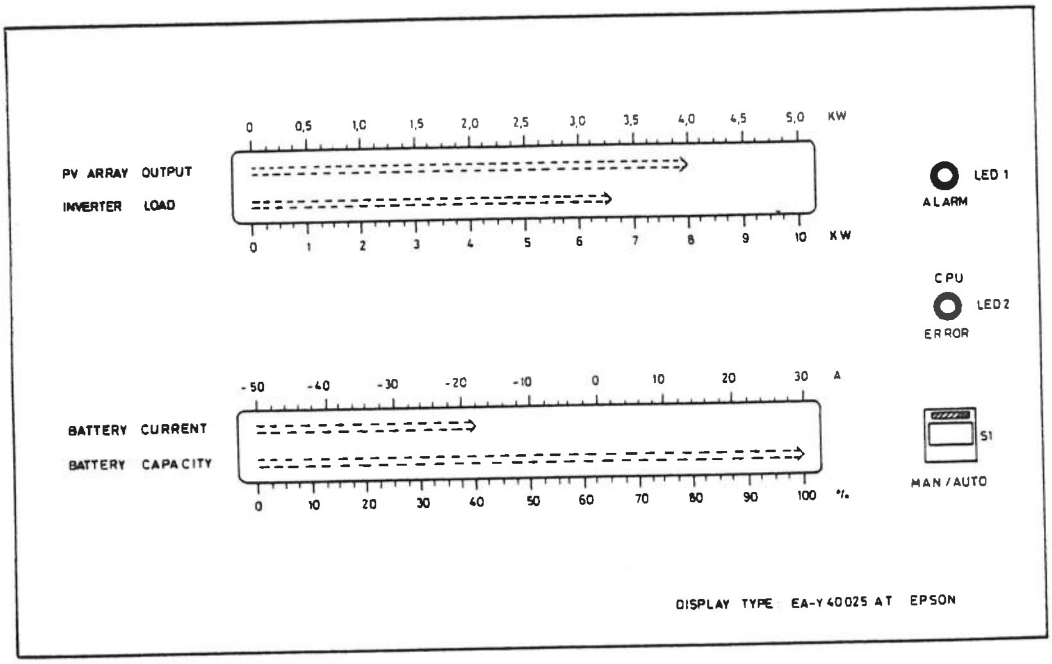


4.3.5.7. Alarm and communication

The DRO generates one or more alarms in case of irregularities in the normal function.

For the users of the house a supervision panel has been mounted indicating by means of a single light emitting diode that there is an alarm condition.
As it appears from the drawing, the panel also shows several superior operating conditions of the house.

Fig. 4.3.5.7.a: Supervision panel. Placed in the kitchen.



In the technique room, at a local terminal connected to the DRO-4 it is possible to have a very detailed general view of alarm conditions, if any, and immediate operating conditions.

The DRO-4 has been equipped with an intelligent modem which in case of alarm condition will call a pre-programmed telephone number to where a terminal with printer is connected (placed at the central administration in Slet near Aarhus). Thus, it is possible to find the time of possible alarms.

Furthermore, the modem connection can be established at ringing to the DRO-4 and thus it is possible to have reports, change parameters, reset alarms, etc.

The alarms for each day and night are registered in the "alarm log" which is stored on a disc.

4.3.5.8. Data registration and collection

The DRO-4 has been equipped with two floppy-disc drives.

One of the drives contains the software for the DRO-4 and in case of total reset of the plant, the DRO-4 will see to the input of the program in the RAM store again.
This makes it possible via modem to make changes in the program, reset and test the change of the program without being present as direct access to read and write on the discs is possible.

The second drive is used for storage of collected data from the plant. Every 5 minutes all data are registered on the disc. One time per 24 hours calculations are made on mean values etc. and these are stored on the disc for later print out of special reports. (Further details later).

5. Evaluation of components.

In the following paragraph an evaluation of the main components in the project is made and the operational experience gained from the operational period is described.

5.1. The house

During the operational period the house has been used two to three times a week for meeting activity.

Thus, as the house has not been permanently occupied during the operational period it has been attempted to simulate a normal family's consumer pattern by means of controlled group outlets in the low voltage installation.
For various reasons this simulation pattern has been changed during the pilot period.

Originally the intention was to supply water heater, fountain pump, electric heating as well as electric lighting and kitchen installations in a real time consumption pattern through the hours of day and night.

However, this consumption would be too large for the pilot plant when this is placed in Denmark. Furthermore, hot-plates as well as the cooker cannot be switched on without supervision.

During recent years the load has consisted of internal lighting as well as a radiant-heating plant placed in the carport. By connecting these groups in appropriate intervals the load has been varied during the day and night. Of course it has been possible to use all the facilities of the house when required.

In this way the load totalled approx. 12 kWh per day and night. The distribution as to time will appear from the load curves shown on page 83 .

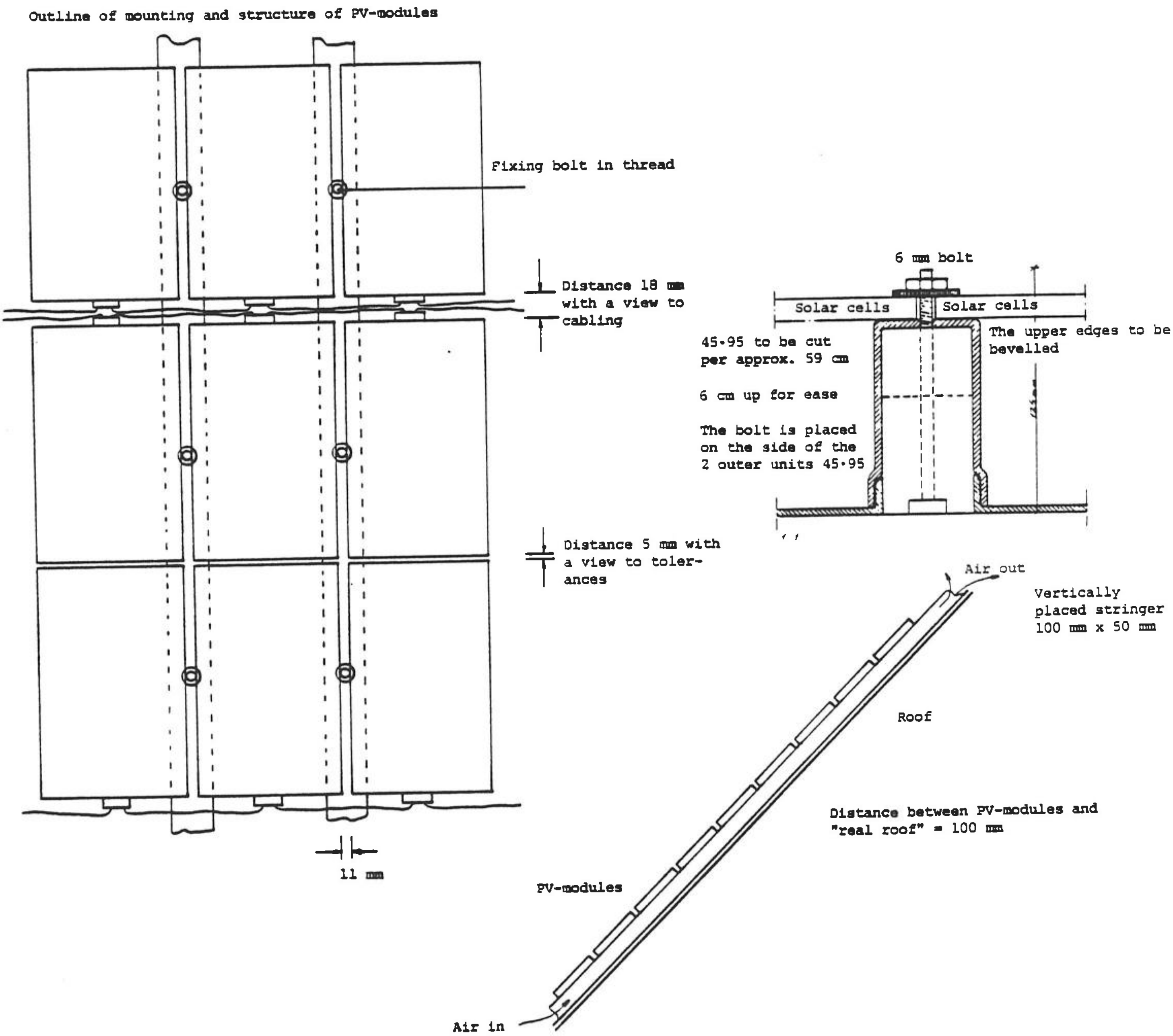
Technically the house has functioned to our entire satisfaction and besides the cracked solar arrays there have been no technical problems.

The utility value, useability and architecture of the house are quite excellent also if possible export to more southern skies is considered.

5.2. The PV-system

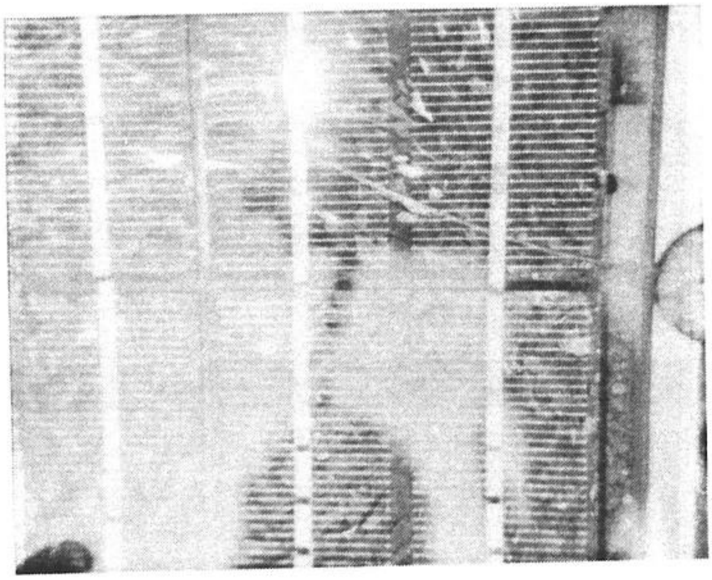
The arrays were mounted on the roof of the house according to the instructions of the supplier.
The mounting was easy and if replacement is required this is possible without too much trouble.

Fig. 5.2.a: Mounting of PV-array.



The mounting with two clamping points and the fact that the arrays were mounted on a new house made of wood is probably the reason why some of the arrays cracked.

Fig. 5.2.b: Crack in cover glass.



The first cracks in the cover glass of the arrays were found immediately after the plant was put into operation and these modules were replaced by new ones.
Another module was replaced owing to electrical faults where the fault was a total disconnection of the module.

Later several cracks have been found in the cover glass of the arrays, so that at the end of the pilot period cracks in the cover glass are found on 8 arrays.

However, the cracks have not resulted in less energy production from the individual strings, but a reduction of the energy production of these arrays must probably be expected in the years to come.

The output from the arrays is stated to be 19.2 W at AM 1 and 25°C. With an effective solar cell area per module of 0.2 m^2 this results in an efficiency of approx. 10%, given the conditions described above.

The efficiency has been measured/calculated to be between 7% and 12% on an average dependent on the time of the year and other external influences. The high efficiency may be due to shadow influences from time to time on the pyranometer from trees in the neighbourhood. See page 47

A decreasing output from the arrays during the 5-year operational period has not been found.

5.3. Rectifier and inverter

The rectifier which originally was not part of the project has charged the battery on the start signal of the DRO when the remaining capacity reached a further fixed limit.

The inverter, developed especially for this project, has functioned satisfactorily during the entire operational period.

The inverter has had no essential faults and has fulfilled our anticipations during the operational phase.
However, the inverter has had a tendency to disconnect the load in connection with sudden major changes of load.

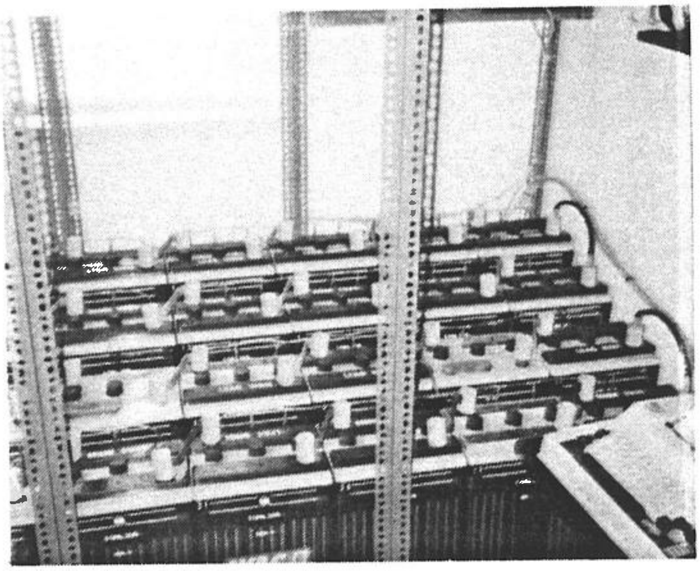
After a minor modification the inverter has been able to resist changes of load without disconnecting the load and has on the whole functioned satisfactorily.

5.4. Battery storage

Antimony-free lead-acid tubular plate batteries have been used for the experiment. This type of battery is excellent for buffer operation where under normal circumstances it is charged to a capacity of 100% and in case of emergency operation it is to be able to supply the rated current.

The plant in Bramming has been equipped with 2 parallel batteries of 200 Ah (C_{10}) each. During charging these batteries were subjected to maximum 21 A per battery and during discharge to approx. 3 A per battery on an average.

Fig. 5.4.a: Battery storage.



In connection with the low load current there is a discharge time of up to 90 hours.

In case of so long discharge times the manufacturer states that the active substance in the positive tubular plate mats may expand so much that this substance leaks from the mats. This phenomenon is especially pronounced when the discharge is close to 100%.

With an effective supervision which with great certainty can prevent that the discharged capacity exceeds the permissible limits this type of battery is probably suitable for use in PV-installations.
It is well-known that the ordinary lead-acid batteries cannot be totally discharged for a long time without being irreparably damaged, why total supervision of the battery in PV-applications is considered a necessity.

The first prototype of the DRO-4 was relatively sensitive to electric noise causing the DRO-4 to reset many times at the beginning of the operational period.

Because of the above the batteries have had several depth discharges of various durations especially during the first period of their lives.

In connection with these depth discharges some of the battery blocks have been damaged in the form of a considerable sulphation and cleansing of active material.
Later it has not been possible to charge these blocks to the same level as the other blocks in the battery why there was a short-circuit in the cells in connection with emergency operation.

In May 1987, a discharge test of the batteries was made. This discharge test showed that it is possible to discharge approx. 80% of the nominal capacity before the expected final voltage was obtained.

At later load tests it turned out that in the batteries there were 3 of the blocks in which there was a severe voltage drop in at least one of the cells. These blocks were replaced in the middle of 1988.

At the subsequent laboratory control of the replaced cells it turned out that these only contained 50-60% of nominal capacity after several chargings and dischargings.
Furthermore, it was found that all positive tubular plates were almost empty of active substance.
These damages are probably due to the depth discharge periods to which the battery was exposed in its early life.

In May 1989, a discharge test was made again corresponding to the one made in 1987.
At the test it was found that there were now 6 new blocks in the batteries with a severe voltage drop after various discharge times and that it was possible to discharge 60% only of the nominal capacity.

Owing to the acid stratification in the batteries and the problems of checking the specific density resulting from this, a bubble device has been mounted in one of the batteries.
After each charging and at least every 100 hours this bubble device bubbles air through the battery in order to have stirring in the electrolyte.

After the expiry of the operational period at the end of 1989, nine battery blocks were taken from the battery and sent to the manufacturer for test at his laboratory.

The nine blocks were:

- 3 blocks without bubble plant (designated UB1, UB2, UB3)
- 3 blocks with mounted bubble plant (MB1, MB2, MB3)
- 3 blocks without bubble plant from the middle of 1987 (UN1, UN2, UN3).

UB and MB have been mounted i the project since start in 1984. UN was those blocks that was changed in middle 1987.

At the reception at the laboratory the following can be found as to the amount of sediment:

Table:5.4.b.

WITHOUT bubble plant: The height of sediment

BATTERY	UB1	UB2	UB3
cell No 1	6mm	8mm	4mm
cell No 2	9mm	6mm	4mm
cell No 3	5mm	5mm	4mm

Table:5.4.c.

WITH bubble plant: The height of sediment

BATTERY	MB1	MB2	MB3
cell No 1	4mm	4mm	4mm
cell No 2	4mm	4mm	4mm
cell No 3	4mm	4mm	4mm

Fig. 5.4.d: Picture of sediment from UB3

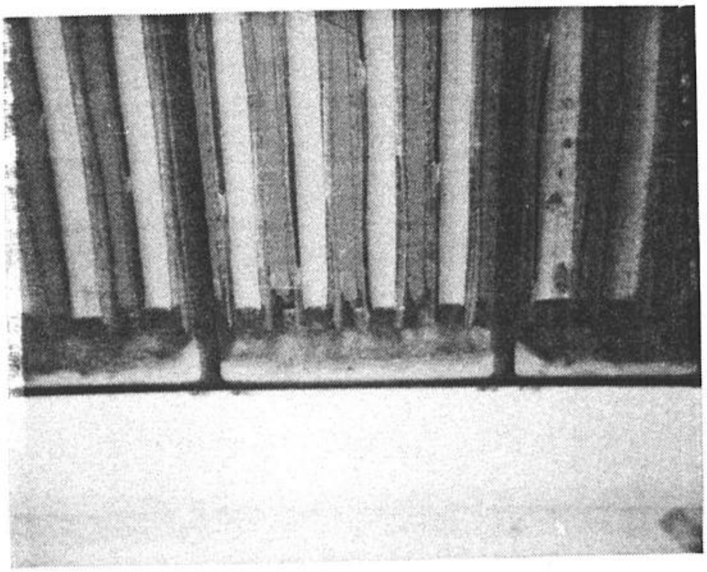


Table:5.4.e.

WITHOUT bubbling newer batteries: The height of sediment

BATTERY	UN1	UN2	UN3
cell No 1	1.5mm	1.5mm	1.5mm
cell No 2	1.5mm	1.5mm	1.5mm
cell No 3	1.5mm	1.5mm	1.5mm

In order to find possible differences in the initial condition of the blocks chosen at random, in defiance of the fact that these were mounted in the plant under the same conditions, the individual block voltages and their individual electrolyte densities were measured. The result appears from the bar charts below:

Fig: 5.4.f.

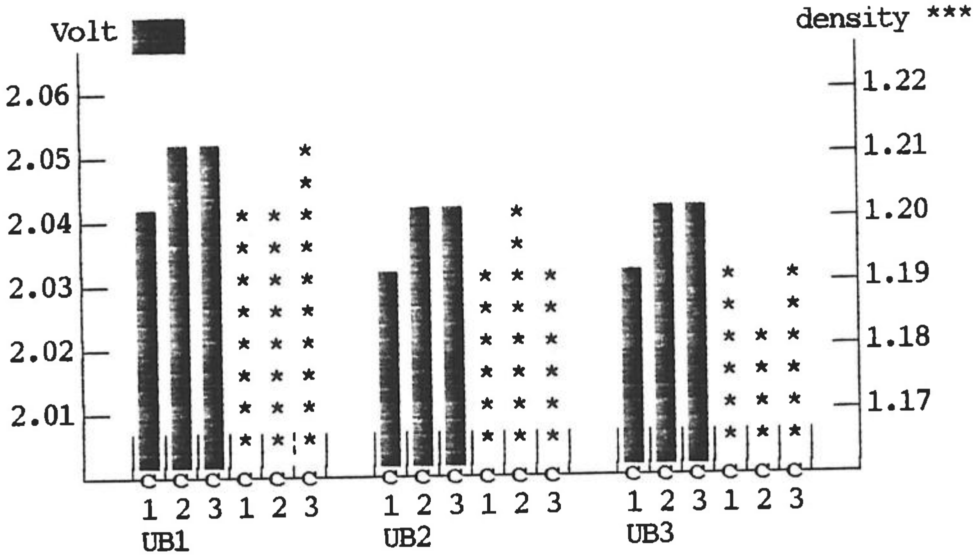


Fig: 5.4.g.

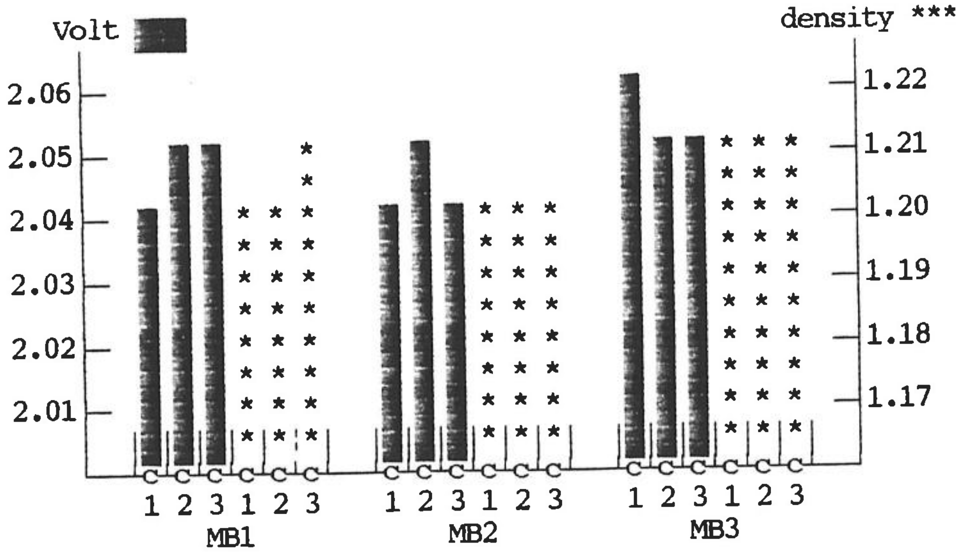
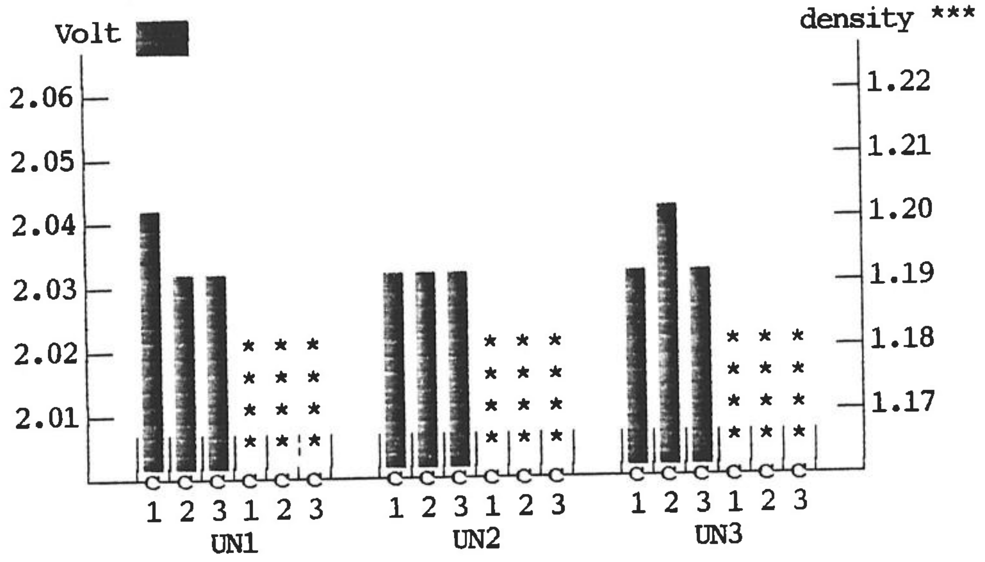
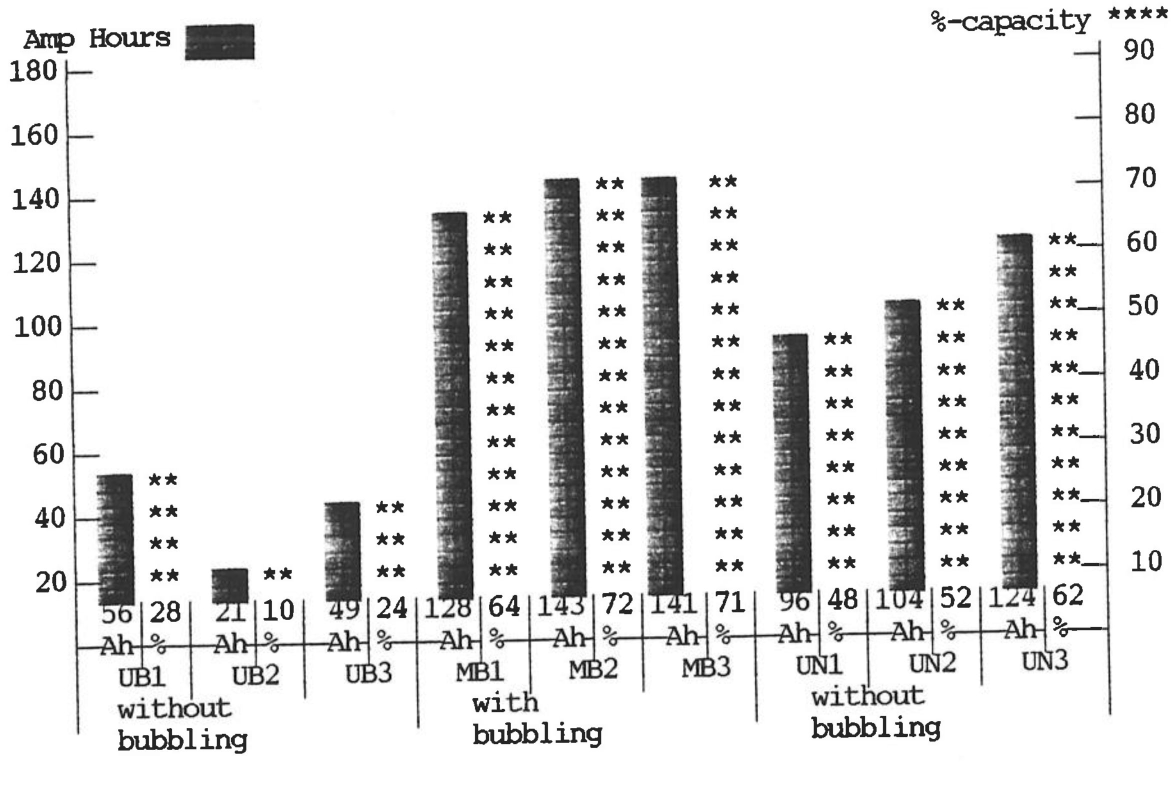


Fig: 5.4.h.



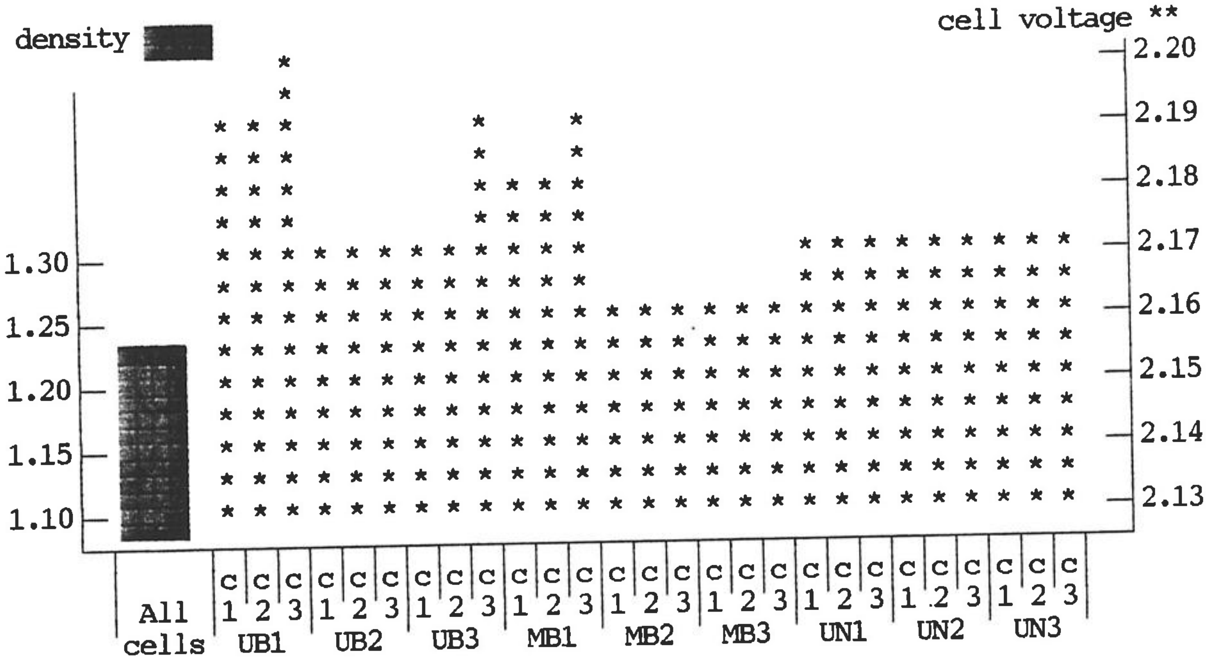
A constant 10-hours' current was used during the capacity test where the following was found:

Fig: 5.4.i.



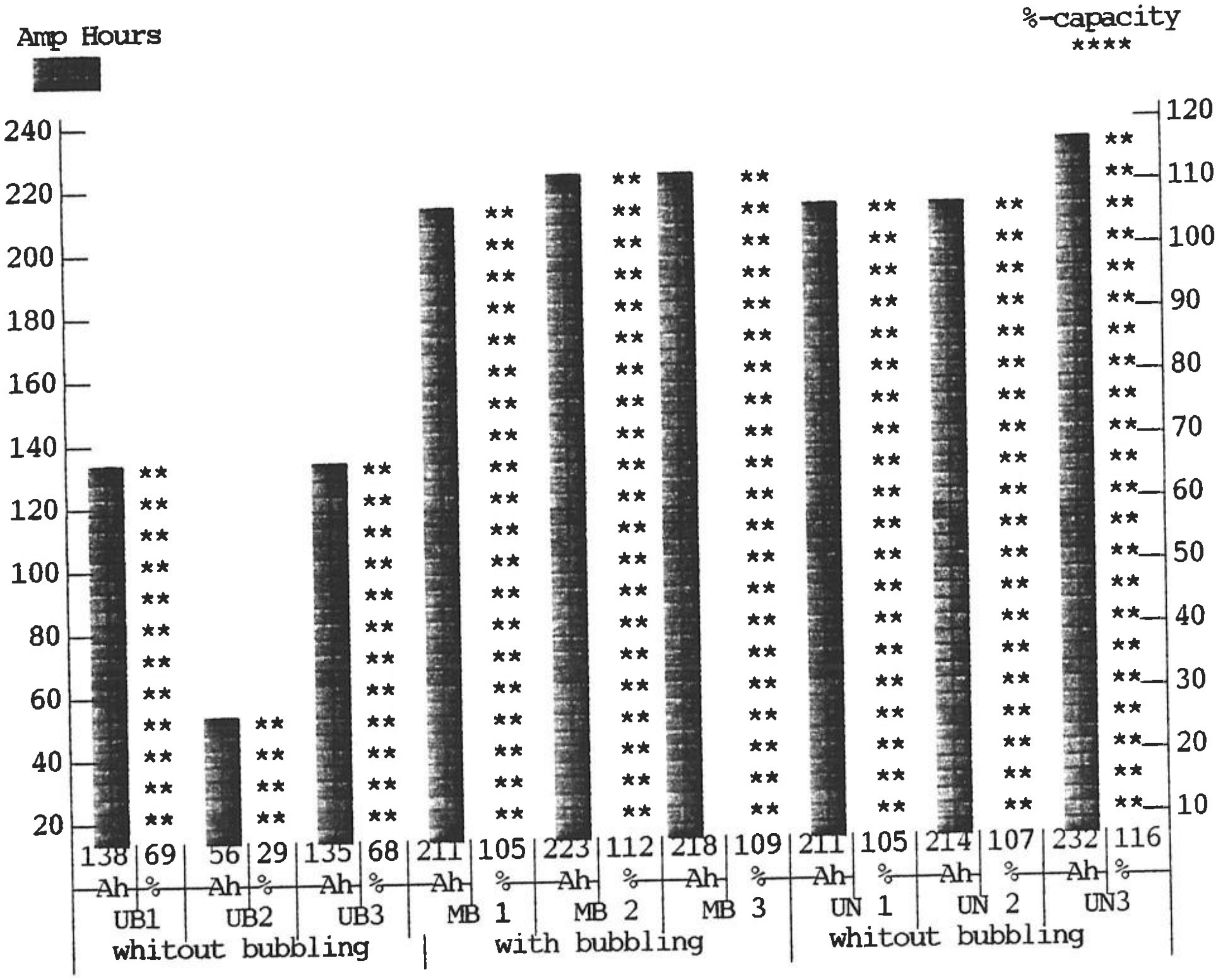
After charging measurements were made again of specific density and cell voltages and the results appear from the below:

Fig: 5.4.j.



At the subsequent capacity test the following was shown:

Fig:5.4.k.



To check the state of the individual cells, positive and negative voltages were measured, respectively, compared to a cadmium electrode:

Fig: 5.4.l.

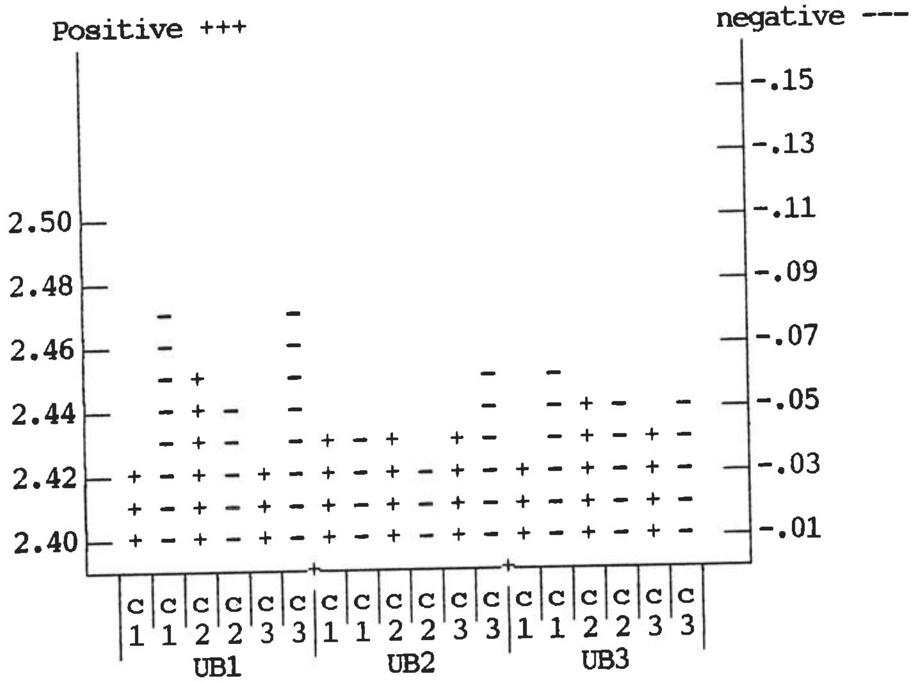


Fig:5.4.m.

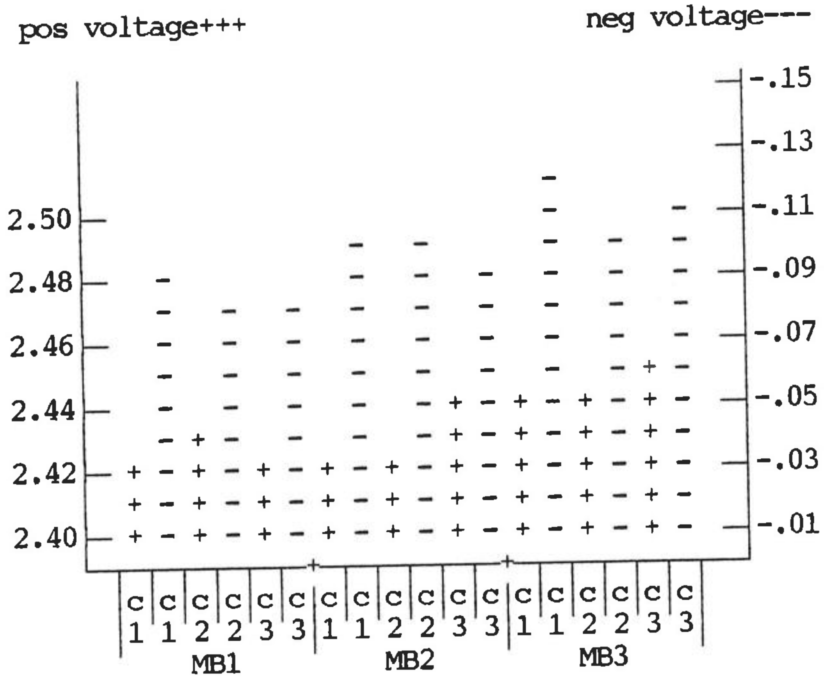
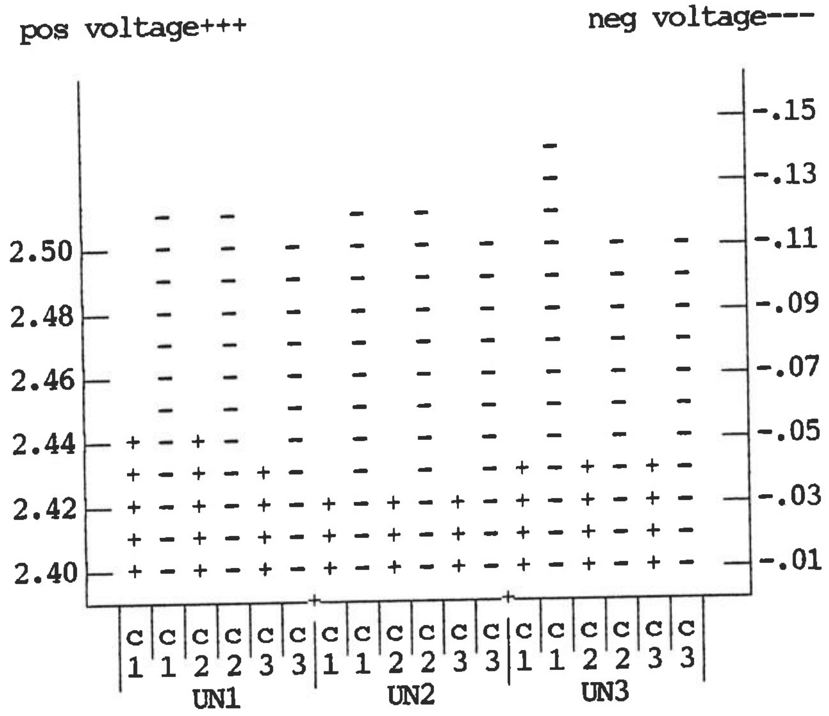


Fig: 5.4.n.


pos voltage+++
neg voltage---
2.50
2.48
2.46
2.44
2.42
2.40
-.15
-.13
-.11
-.09
-.07
-.05
-.03
-.01
c 1
c 1
c 2
c 2
c 3
c 3
UN1
UN2
UN3

After separation of the battery blocks the following can be found:

UB1:
- Negative plates: Plates OK
- Positive plates: 7.0 cm of tube is emptied as sediment
  All bottom strips were cracked

UB2:
- Negative plates: Plates OK - faint marks of sulphate
- Positive plates: 1.5 cm of tube is emptied as sediment
  All bottom strips were cracked

UB3:
- Negative plates: Plates OK - faint marks of sulphate
- Positive plates: A lot of sulphate on surfaces
  All bottom strips were cracked

MB1:
- Negative plates: OK
- Positive plates: No sediment
  Some corrosion damage at the top edge

MB2:
- Negative plates: OK
- Positive plates: 2.0 cm of tube is emptied as sediment
  Some corrosion damage at the top edge

MB3:
- Negative plates: OK
- Positive plates: 1.0 cm of tube is emptied as sediment
  Bottom list somewhat damaged

UN1:
- Negative plates: OK
- Positive plates: The plates are not expanded at the top 50%

UN2:
- Negative plates: OK
- Positive plates: The plates are not expanded at the top 30%

UN1:
- Negative plates: OK
- Positive plates: The plates are not expanded at the top 50%.

Fig. 5.4.o: Picture of sulphate stripes UB3

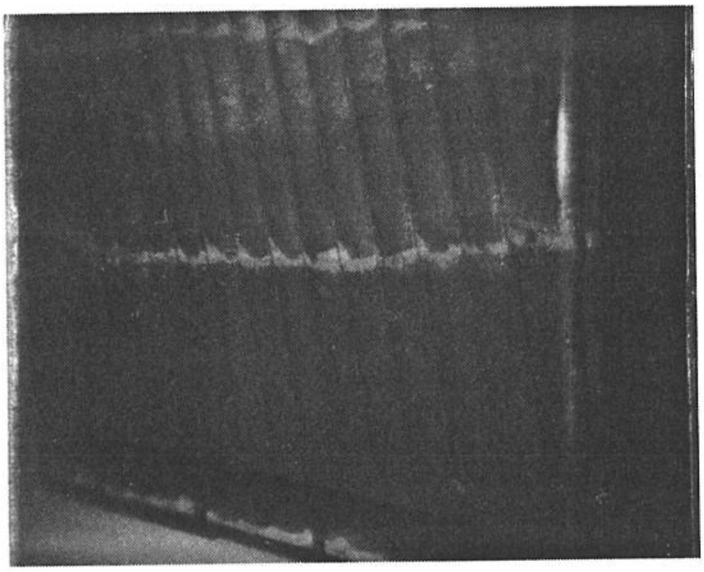
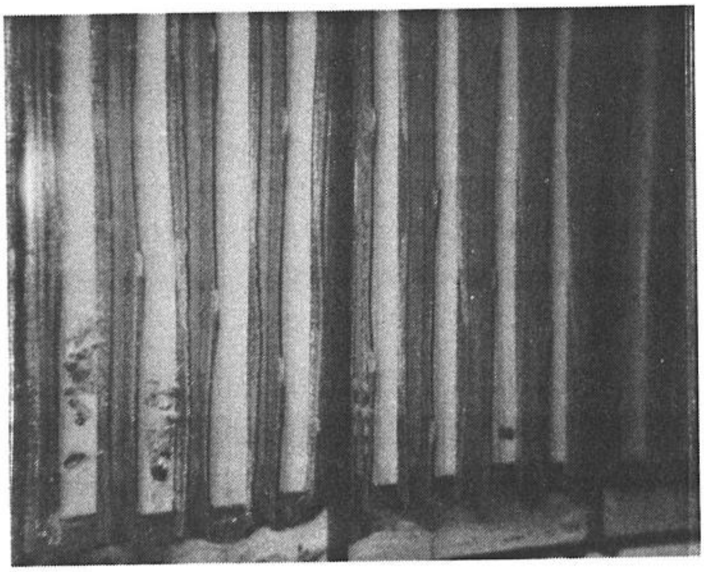


Fig. 5.4.p: Picture of broken tubes UB2.



Summary of the measuring results:

The purpose of the examinations was to have indications for:

- Does the bubble plant improve the life of the battery.
- Are the batteries in this application after five years of operation in a poorer state than batteries of the same age applied in a conventional stand-by application.

It appears rather clearly from the initial examinations that what has been emptied as sediment is considerably more for the blocks which have been installed during the entire operational period than the recently installed blocks (UN). Furthermore, it is indicated that what was emptied as sediment in the blocks mounted with bubble plant (MB) was less than in the blocks without bubble plant (UB).

The initial voltage measurements indicate that all blocks had approximately the same voltage at no load and thus the latest operational conditions have been the same. The subsequent capacity test (fig. 5.4.i) shows very clearly that the capacity contents of the blocks without bubble plant (UB) is considerably less than the others.

After the first discharge all blocks were charged with nominal power for nominal time and the voltages at no load were measured again (Fig. 5.4.j.). It should be noted that there are considerable spreadings in the cell voltages of the "old" blocks. At the subsequent capacity test (Fig.5.4.k.) it appears clearly that the blocks which have not been bubbled have a capacity state which is much poorer than the others.

From measuring of positive and negative poles compared to a cadmium electrode (Fig. 5.4.l-n) it appears from the measuring results that the poor blocks (UB) have very low voltages from the negative electrode indicating that these may be sulphated.

At the subsequent separation of the blocks indications of sulphate was found on the UB-blocks. Furthermore, no indications of serious corrosion were found on any of the blocks. Especially, it should be noted that the "new" blocks (UN) showed pronounced indications of the effects of heavy stratification as only the lower part of the plates participates in the chemical reaction in the battery. Owing to this, periodic "exercise" of the battery must be recommended in connection with considerable dischargings and chargings if no bubble plant is installed.

5.5. Supervision equipment DRO-4

The first model of DRO-4 which was put into operation in 1984 had several disadvantageous facilities i.a. a relatively poor electric noise immunity to noise pulses from outside.

Furthermore, the data collection units were not of the expected quality.

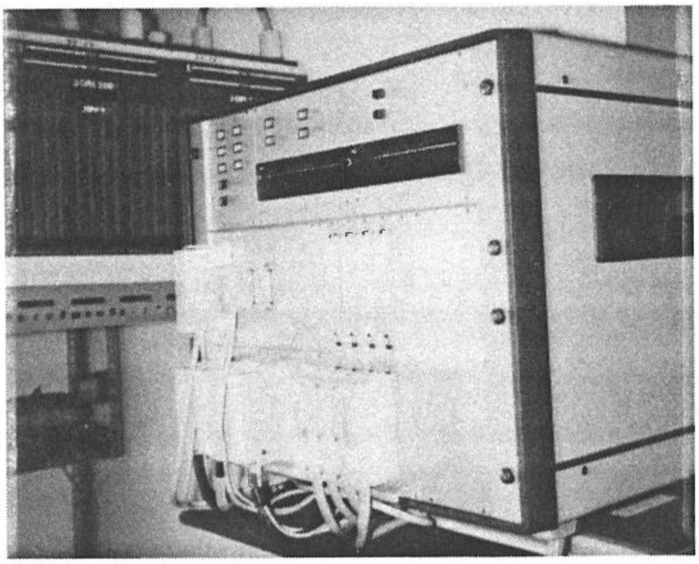
Owing to these problems of the first DRO, the DRO-4 reset several times during the first time of the operational period. When this version of the DRO-4 reset, it did not store i.a. the calculated value of the actual capacity but stated it to be 100%.

Thus, it has happened several times that the remaining capacity really was very small and the DRO-4 indicated that this was not the case.

As previously mentioned the disc drives were not of a quality which guaranteed a continuous data collection, and thus several operational data are missing for the first period of the operational phase.

On the basis of the operational experiences gained, a new version of the DRO-4 was developed and installed at the beginning of 1986.

Fig. 5.5.a: Picture of DRO-4



Besides an improved immunity to electric noise various improvements of the software had been made on the new DRO-4 enabling it to calculate the capacity at a greater accuracy when the discharging currents are low.
Simultaneously the software was improved in order to store the actual capacity and use this value after a possible reset.

Owing to a fault in the relay of the DRO-4 this was exposed to some damaging overvoltages. Four printed circuit boards burnt because of these overvoltages. Data disc and disc drives were damaged and thus collected operational data for a specific period were lost because of the heat development in the DRO.

Disc drive and printed circuit board were replaced and the DRO was put into operation again at the beginning of 1987. All data were transferred via the telephone line once a month from the beginning of 1987 to secure the collected data.

The present version of the DRO-4 is now a reliable unit which is able to supervise and control the PV-pilot plant continuously.

5.6. Other equipment

5.6.1. Irradiation meters

Approx. 20 m from the house a pyranometer, manufactured by the firm of Kipp & Zonen, was mounted for measurement of the sun irradiation.
Via an amplifier the measuring signal from here was collected and stored by the DRO-4. There have been no faults in this function in connection with the operation.

The pyranometer has been placed in a natural windbreak which at the time of placing was about 1 m high. In five years this windbreak grew to be more than 4 m high.
Owing to the placing in the middle of this windbreak, shadow influences from the windbreak were found last summer.

Owing to this shadow the pyranometer has showed too low values and consequently the DRO has calculated a too large efficiency of the solar arrays.
By reducing the height of the windbreak this problem has been solved.

5.6.2. Dc switches

The output voltage of the PV-modules which is applied directly on the battery has been kept within acceptable limits by means of on/off connection of solar strings.

The control of these connections is made by the DRO on the basis of a measured battery voltage. During the operational period the principle has functioned without problems.

By changing the connection and disconnection limits in the software it has been possible to choose values which almost could give maximum power from the solar arrays without over-charging the battery.

In recent years the connection and disconnection voltages have been adjusted to 255 V and 259.9 V, respectively, measured on the battery.

5.6.3. Connection and disconnection of consumption groups

Control of the load pattern has taken place by connection and disconnection of consumption groups.

This control has been made by programming the timers of the DRO to connect with the groups at further fixed times.

The control has been without problems and has been very easy to operate.

6. The operational period

6.1. Operational report

Brief survey of the operational progress.

The plant was put into operation at the end of 1984.

6.1.2. Period: end of 1984 to the middle of 1986:

6.1.2.1. The PV-array. Technical and mechanical faults have been detected on the arrays. 7 modules were replaced in February 1986. One because of total disconnection and six because of cracks in the cover glass.

6.1.2.2. Power conditioning equipment. Owing to experience with corresponding equipment in another project, the inverter has been modified as regards mechanic and supervision.
The control functions have been modified so that the inverter is able to resist considerable load changes without disconnecting. After the modifications the inverter has functioned to our entire satisfaction.

6.1.2.3. The battery storage. In spite of general problems of operation with the entire plant, attempts have been made to keep the batteries charged during the period.
No operational problems with the batteries have been found. However, a tendency to sediment was found and a single block short-circuited at load. A bubble device has been mounted which blows air through one battery after charging.

6.1.2.4. DRO. The DRO has been somewhat defective. Especially considerable electric noise sensitivity as well as data collection have been a problem. The result was that the entire DRO unit was replaced at the beginning of 1986.

6.1.3. Period: The middle of 1986 to the beginning of 1987:

The plant has functioned satisfactorily until the turn of the year when four printed circuit boards in the DRO burns. The reason was a relay which failed. The generation of heat damaged four analog printed circuit boards as well as the data collection disc. The DRO is repaired and remounted in February 1987.

6.1.4. Period: The beginning of 1987 to the end of 1989:

6.1.4.1. The PV-array. Cracks were found on the cover glass of another eight modules. In spite of these cracks, the output from the strings, containing these modules, do not seem to decrease why the arrays are not replaced.

Some alarms have occurred from the arrays lately. The alarms occur owing to differing production from the individual strings. The alarms occur typically early in the morning and disappear after a few minutes.
Maybe these alarms may be due to poor connections in conjunction with heating of the individual strings. However, the alarms do not occur from the same strings every time.
Furthermore, alarms in connection with partial snow-cover of the lower arrays are found.

In the spring of 1988, the efficiency of the array began to increase towards 18%. An examination showed that where the pyranometer is placed the windbreak (planted at the beginning of the project of 84) is now so high that it shades the measuring equipment.
The result is too small values of the irradiation measurements and consequently a too large efficiency. The windbreak was trimmed and later (at the beginning of 89) the pyranometer was removed from the windbreak and placed near the house.

6.1.4.2. Battery storage

As a result of occasionally lacking supervision especially at the beginning of the project the battery has been exposed to several depth discharges of a long duration at the beginning of its life.
Originally it was decided that the battery should function within the range of 100% and 20% capacity. However, since there have been some problems with the security so that the supervision could determine the capacity accurately it was decided in the middle of 87 to change the range to 100%-50%. This implies that the dimensioned size of the battery is changed artificially to a minor value. Of course this influence the energy taken from the mains, as this is not an optimized buffer size.

From the start of the project until the beginning of 1988 the load on the plant has been approx. 5 kWh/24 hours. The load is changed to approx 10 kWh/24 hours and in the middle of 1988 to approx. 17 kWh/24 hours.

After this increase of load the battery shows more faults in connection with discharges. Especially a lightning in the house in the middle of 1988 which temporarily inactivated the DRO caused a considerable depth discharge. Several days passed before the battery was recharged and after this several problems occurred with more of the cells which short-circuited at load.
Three blocks are replaced for examination at the firm of Lyac Power.
The result of this examination showed that the actual blocks only had approx. 50% of their original capacity. Furthermore, it was found, as expected due to the above-mentioned treatment, that all positive plates were halfway empty of lead substance.

In the middle of 1989, the battery was subjected to a charging test showing that the battery after discharge with approx. I(50) reached its supposed final voltage of 1.85 after approx. 320Ah has been discharged. This corresponds to a capacity of approx. 65%.
A corresponding test at the beginning of 1987 showed that the battery at that time had a nominal capacity of approx. 80%.
Generally it can be concluded that the battery has been exposed to extreme conditions in its early life which caused the reduced contents of capacity.
However, during the experiment the DRO has been improved to such a degree that by using a better calculation of capacity it is possible to avoid further depth discharges in the remaining pilot period.

6.1.4.3. Power conditioning equipment: After the previously mentioned modifications there have been no problems with this equipment.

6.1.4.4. DRO: There have been some faults on some of the analog measuring inputs measuring on the inverter output. However, these faults were found quickly and corrected so they have not influenced the collected data.
From the end of 1987 until the beginning of 1988 faults on the measurement of the supplement from the mains have been found. The result was that the supplement from the mains has not been registered in the period mentioned.
However, in the survey report it has been possible to recreate the value of this supplement which occurred in January 1988 by means of information about capacity increase on the battery.

6.2. Data collection report

Referring to the data collection report overleaf the individual data will be explained. The figures refer to the line numbers on the report example on page 54

0: Dc BUS MEAN

Measurement is carried out directly via an input in the DRO. The voltage is measured every minute and on the basis of five measurements, a 5-minute simple mean value is calculated which is stored on a disc. Every 24 hours the mean value of the collected data is calculated.

1: INVERTER OUTPUT

By means of a DEIF WATT converter, mounted on the output of the inverter, the output of the inverter is converted into a voltage signal, registered by the DRO. The output of the inverter is measured every 10 seconds. The values registered are summarized every five minutes and stored on a disc. Every 24 hours a total summary of the 5-minute values are made.

2: RECTIFIER OUTPUT

The rectifier output is measured as 220 V dc. This signal is voltage divided to approx. 10 V which together with a shunt signal from the rectifier output is transferred to an analog calculating unit which carry out the product of the two signals. This product (0-2.5 V) is transferred to the DRO. Therefore, the consumption of the rectifier from the mains has not been taken into consideration, but only the energy which the rectifier supplies to the system. The output is calculated continuously and is scanned once every 10 seconds. Every five minutes a sum of the energy is calculated and stored on a disc. Every 24 hours the total sum of the output of the rectifier is calculated.

3: PV OUTPUT

There is a shunt for each of the nine strings. These shunts are scanned every minute. Every five minutes the sum of the energy produced is calculated and stored on a disc. Every 24 hours the total energy from the PV-arrays is calculated.

4: PV SURPLUS

Adjustment of the PV-production takes place as previously mentioned by disconnecting a number of strings when the voltage is too high on the battery. By measuring the production which the connected strings produce and compare this figure with the number of connected strings, it is possible to calculate the theoretical production of the disconnected strings. These

calculations take place every minute and the sum of five calculations are stored on a disc. Every 24 hours the total energy which the disconnected strings represent is calculated.

5: PV EFFICIENCY

On the basis of the signal concerning the sun irradiance and by comparing this value with the actual production from the PV-arrays, the efficiency is calculated as the sun irradiation divided by the area of the connected arrays. If the sun irradiance at the moment of measuring is less than 50 W/m², the calculation is omitted. The calculations are carried out every minute and every five minutes a simple mean value is calculated which is stored on a disc. Every 24 hours a simple mean value is calculated.

6: INSOLATION PLANE

The sun irradiance is measured by a KIPP & ZONEN CM5/6. The signal from here is transferred to an amplifier which amplifies the 11mV signal to 2.5 V which is scanned by the DRO every minute. Every five minutes the values are summarized and stored on a disc. Every 24 hours the total sum of irradiation is calculated.

7/8: CAPACITY BATTERY

The current to and from the battery is measured via a shunt every 10 seconds. By means of advanced algorithms capacity changes are calculated every 10 secs. The actual capacity of the batteries is calculated. Every five minutes a simple mean value is calculated which is stored on disc. Every 24 hours the simple mean value of the capacities is calculated.

9/10/11/12: PV-TEMPERATURE

A PT100 temperature detector is integrated in one of the PV-arrays. Signals from here are transferred directly to the DRO. Every five minutes a simple mean value is calculated and stored on a disc. Every 24 hours an average temperature is calculated. The mean values from 6 a.m., noon, 6 p.m. are stored directly.

13/14/15/16: OUTDOOR TEMPERATURE

A temperature detector is mounted in the carport. The values are collected as mentioned under PV-temperature.

17/18/19: PV-VARIANCE

On the basis of the individual values for the string production the variance is calculated. The value is used daily to check whether the variation in the string production is too large and then report the fault. The values from 6 a.m., noon, 6 p.m. are stored on a disc.

20/21: ELECTROLYTE TEMPERATURE

In one pilot cell in each battery a KTY temperature detector has been mounted. The value from here is transferred directly to the DRO which scans the value every minute. Every five minutes a simple mean value is calculated which is stored on a disc. Every 24 hours a simple mean value of the collected data is calculated.

22/23: ELECTROLYTE LEVEL

In one pilot cell in each battery a mechanic/electric level detector has been mounted. The signals are processed by the DRO-4 and stored on a disc.

24-37: BLOCK VOLTAGE

The total number of blocks of each battery is scanned every minute for individual block voltage. On the basis of this a simple mean value is calculated every five minutes and the major and minor value found are stored on a disc. Every 24 hours the maximum and minimum values from 6 a.m., noon, 6 p.m. are stored and the mean value of the day is calculated.

ALARM LOG:

The DRO is able to report 56 individual alarms. In the alarm log the code of the individual alarms, sent during the 24 hours, is seen. Survey of these alarm codes appears from page 55

Table 6.2.a: Data collection report

DATE	890828	890829	890830	890831	890901	890902	890903	890904	890905	
0 DC BUS MEAN	236.1	226.0	222.7	229.2	233.9	226.7	225.1	225.6	221.2	V
1 INVRT.OUTPUT	22.0	19.0	18.0	17.1	16.6	16.4	16.5	16.4	16.5	KWh
2 RECTF.OUTPUT	59.2	0.0	0.0	55.7	5.6	0.0	0.0	0.0	0.0	KWh
3 PV OUTPUT PW	18	22	12	2	22	20	18	24	8	KWh
4 PV SURPLS PW	0	0	0	0	0	0	0	0	0	KWh
5 PV EFFICIEN.	9	9	10	12	9	9	9	9	8	%
6 INSOL.PLANE	4.3	4.8	2.3	0.3	4.8	4.3	4.0	5.3	1.9	KWh/m
7 CAPACITY, I	92	86	67	100	96	91	83	83	62	%
8 CAPACITY, II	87	81	63	100	93	88	80	80	60	%
9 MEAN	21.7	23.8	22.6	20.2	26.0	24.5	23.8	24.9	20.2	GRC
10 VALUE AT 6	23.0	10.3	14.8	18.8	16.4	16.8	11.9	12.5	14.9	GRC
11 VALUE AT 12	42.2	49.1	33.8	20.0	39.3	31.8	54.0	47.8	23.2	GRC
12 VALUE AT 18	27.1	30.2	25.9	21.4	28.7	29.8	24.5	29.2	25.1	GRC
13 MEAN	14.0	15.3	16.7	17.1	16.7	16.0	15.1	15.0	15.4	GRC
14 VALUE AT 6	13.3	10.4	11.7	15.8	13.4	14.3	10.6	11.1	12.1	GRC
15 VALUE AT 12	15.7	18.8	18.6	16.8	19.1	17.5	18.5	17.2	16.7	GRC
16 VALUE AT 18	17.8	19.2	21.6	19.9	19.5	18.1	18.8	18.4	18.9	GRC
17 VALUE AT 6	999.9	999.9	970.9	999.9	950.0	999.9	999.9	999.9	996.1	
18 VALUE AT 12	99.9	1.9	3.2	11.0	6.9	3.0	4.0	1.6	3.6	
19 VALUE AT 18	8.3	17.8	32.1	999.9	10.2	11.8	27.5	12.1	11.3	
20 ELECT.TMP I	26.3	25.7	24.9	24.6	26.4	25.2	24.3	24.0	23.4	GRC
21 ELECT.TMP II	30.1	29.2	27.9	27.4	29.9	28.3	27.2	26.8	26.1	GRC
22 ELECT.LVL I	69	70	66	66	71	69	66	64	63	%
23 ELECT.LVL II	15	11	11	11	13	13	9	9	8	%
24 MEAN	6.580	6.299	6.209	6.389	6.521	6.319	6.275	6.288	6.169	V
25 HIGH AT 6	6.541	6.269	6.244	6.186	6.466	6.285	6.258	6.232	6.234	V
26 LOW AT 6	6.332	6.169	6.144	6.083	6.255	6.180	6.158	6.136	6.131	V
27 HIGH AT 12	6.591	6.512	6.362	6.200	6.493	6.480	6.500	6.517	6.178	V
28 LOW AT 12	6.413	6.416	6.268	6.103	6.324	6.382	6.405	6.421	6.065	V
29 HIGH AT 18	6.453	6.323	6.163	6.661	6.386	6.363	6.232	6.323	6.152	V
30 LOW AT 18	6.240	6.200	6.063	6.499	6.195	6.213	6.128	6.193	6.039	V
31 MEAN	6.580	6.299	6.209	6.388	6.520	6.318	6.274	6.288	6.168	V
32 HIGH AT 6	6.480	6.271	6.242	6.184	6.357	6.280	6.260	6.234	6.231	V
33 LOW AT 6	6.363	6.160	6.135	6.072	6.269	6.176	6.149	6.120	6.122	V
34 HIGH AT 12	6.569	6.509	6.359	6.197	6.433	6.478	6.503	6.512	6.180	V
35 LOW AT 12	6.437	6.415	6.263	6.085	6.348	6.381	6.398	6.415	6.059	V
36 HIGH AT 18	6.344	6.303	6.169	6.588	6.301	6.323	6.231	6.307	6.150	V
37 LOW AT 18	6.263	6.210	6.049	6.494	6.223	6.230	6.118	6.208	6.028	V

ALARM LOG:

Table 6.2.b: Alarm survey

LIST OF DRO-4 ALARM CODES

001 - 025	Block voltages,	battery 1
026	Battery voltage,	-
027	Electrolyte temp.	-
028	Electrolyte level	-
033 - 057	Block voltages,	battery 2
058	Battery voltage,	-
059	Electrolyte temp.	-
060	Electrolyte level	-
065 - 075	Block voltages,	battery 1
076 - 086	Block voltages,	battery 2
088	Insolation	
090	DC bus voltage	
091	Photovoltic temperature	
104	Rectifier output power	
106	Inverter output power	
107	DC load current	
108	Photovoltic output current, all strings	
109 - 117	Photovoltic output current, each string	
118 - 121	Battery currents, +/- and batt. 1/2	
123	Outdoor temperature	
200	Low capacity,	battery 1
201	Charging impossible,	-
202	Time limit, state 3,	-
203	Time limit, state 4,	-
204	Rising charging current,	-
210 - 214	Corresponding alarms,	battery 2
220	Fuse,	inverter
221	Voltage,	-
222	Frequency,	-
223	Low batt.volt.	-
224	Error,	
230	Fuse,	rectifier
231	Overvoltage,	-
232	Undervoltage,	-
233	Failure,	-
241-249	PV string deviation	
300	Generel minor alarm	
997	Data recording eror	
998	Reset, memory error	
999	Reset, memory ok	

6.3. Operational data 1988-1989

As previously mentioned, data have been collected every day during the entire pilot period.
Owing to the clearness only data from the last two years are included.

6.3.1. On the following pages the collected data are presented on a form recommended by WIP (Wirtschaft und Infrastruktur GMBH & Co. Planungs-KG Munich).

In order to understand the forms and describe the calculation methods of the individual figures you will find a brief description of the individual items in the form.
Figures in parenthesis "[x]" refer to the line numbers in previous data collection reports and the figure/letter combination refers to line number in the survey report.
An "?n?" in the survey report indicates that no data are available for the month in question or that it has not been possible to calculate the actual value.

1.a.: Sum[6] for actual month.
1.c.: Mean[6]/24h for actual month.
1.f.: Mean[9] for actual month.
At 6 pm:Mean[10] for actual month.
At 12 pm:Mean[11] for actual month.
At 6 am:Mean[12] for actual month.
1.h.: Mean[13] for actual month.
1.i.: Min([14][15][16]) for actual month.

2.a.: Sum[3] for actual month.
2.b.: Sum[1] for actual month.
2.c.: Mean[3]/24h for actual month.
2.e.: Mean[1]/24h for actual month.
2.h.: Sum[4] for acutal month.

3.a.: Sum[3] + sum[4] for actual month.
3.b.: Sum[3]/(3.a.) for actual month.
3.c.: Mean[5] for actual month.
3.e.: (6.a.)/((6.c.)+(2.a.)) * 100
3.f.: (Days with collected data)/(days in actual month)

4.a.: Mean([7] [8]) for actual month
4.b.: Number of days where (4.a) < 95%
4.c.: Mean([20] [21]) for actual month
4.f.: Mean([22] [23]) for actual month

5.a.: As 3.f.
5.c.: As 3.f.
5.d.: Number of days without data collection in actual month

6.a.: (2.b.)
6.b.: 3.120 kWH * (number of days in actual month) - (5.d.)
6.c.: Sum[2] for actual month

Table 6.3.1.a: Data 1988/1.

PV pilot plant:PV-house Bramming
Site manager:M.Jørgensen
Project manager:B.Mortensen

Date of report:890920
Prepared by:M.Jørgensen
Telephone:+4586293366 ext.4205
YEAR : 1988

Latitude (N): 56
Longitude (E): 9
Altitude (m): 30

PARAMETER	UNITS	JAN.	FEB.	MARCH	APRIL	MAY	JUNE
1.Solar/temperature							
a:Insolation Energy.Plane of array	kWh/m2	11.7	31.3	71.8	121.8	146.2	89.7
c:Irradiance.Plane DayAvg(24h)	W/m2	16.8	45.0	96.5	169.2	196.5	143.8
f:Temperature, back of PV-module DayAvg	degree	9.5	9.2	7.9	14.2	23.9	27.5
at 6 pm	degree	8.1	6.8	4.7	6.2	12.6	17.4
at 12	degree	11.8	14.0	17.8	30.1	39.0	40.6
at 6 am	degree	8.8	9.7	9.2	18.0	28.7	31.7
h:Temperature. Ambient DayAvg	degree	4.2	3.2	3.4	6.9	13.9	17.3
i:Temperature. Ambient DayLow	degree	0.6	0.0	0.0	0.0	5.2	9.9
2:Plant Output Information							
a:Energy, Array Field, Used	kWh	55.0	139.0	288.0	378.0	540.0	470.0
b:Energy, Inverter	kWh	44.5	174.4	167.2	131.5	301.8	400.8
c:Power, Array DayAvg(24h), used	kW	0.08	0.19	0.39	0.53	0.73	0.75
e:Power, Inverter DayAvg(24h)	kW	0.06	0.25	0.22	0.18	0.39	0.64
h:Energy, Array Field, NoConnect	kWh	0.0	3.0	27.0	147.0	96.0	28.0
3:Plant Performance Indices							
a:PV Array Energy Cabability	kWh	55.0	142.0	315.0	525.0	636.0	498.0
b:Array Utillization Factor	%	100.0	97.9	91.4	72.0	84.9	94.4
c:Array Energy Efficiency (Irrad.>50)	%	4.4	7.5	8.2	8.2	8.8	12.6
e:System Energy Efficiency DayAvg	%	21.3	33.6	35.2	32.6	52.9	54.7
f:Plant Availability	%	93.5	100.0	100.0	100.0	100.0	86.7
4:Battery Information							
a:DOD,% rated Ah, DayAvg	%	86.8	88.7	89.6	92.3	93.1	87.2
b:No cycles, DOD-Avg>5%	no	25	23	27	16	9	17
c:Cell Temperature, DayAvg	degree	17.4	20.7	22.4	23.0	26.1	28.1
f:Level electrolyte DayAvg	%	92.1	88.8	83.3	78.2	74.0	68.4
5:Operation and Maintenance Information							
a:Percent of total time DRO operational	%	93.5	100.0	100.0	100.0	100.0	86.7
c:Percent of total time Inverter operational	%	93.5	100.0	100.0	100.0	100.0	86.7
d:Number of failures and MTTR							
for major components							
1)number	no	2.0	0.0	0.0	0.0	0.0	4.0
2)MTTR	h						
6:Application Information							
a:Comsumer (Load) Energy, sum.	kWh	44.5	174.4	167.2	131.5	301.8	400.8
b:System consumption, sum.	kWh	90.5	90.5	96.7	93.6	96.7	81.1
c:Energy from Grid to PV plant, sum.	kWh	154.3	379.5	186.9	25.8	30.3	262.6

Table 6.3.1.b: Data 1988/2.

PARAMETER	YEAR : 1988 UNITS	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
1.Solar/temperature							
a:Insolation Energy.Plane of array	kWh/m2	95.7	93.7	62.0	17.8	44.2	16.4
c:Irradiance.Plane DayAvg(24h)	W/m2	128.6	125.9	86.1	28.5	61.4	22.0
f:Temperature, back of PV-module DayAvg	degree	25.1	24.6	21.2	15.5	10.3	9.6
at 6 pm	degree	17.8	17.3	15.1	11.0	7.4	8.2
at 12	degree	33.6	37.0	32.5	25.2	20.3	13.9
at 6 am	degree	28.7	27.7	23.5	13.7	8.0	9.0
h:Temperature. Ambient DayAvg	degree	18.2	17.6	15.1	9.5	5.8	5.9
i:Temperature. Ambient DayLow	degree	12.4	10.1	8.3	-2.0	-3.9	-2.1
2:Plant Output Information							
a:Energy, Array Field, Used	kWh	498.0	462.0	348.0	109.0	208.0	85.0
b:Energy, Inverter	kWh	565.2	536.6	560.6	130.0	397.4	464.8
c:Power, Array DayAvg(24h),used	kW	0.67	0.62	0.48	0.17	0.29	0.11
e:Power, Inverter DayAvg(24h)	kW	0.76	0.72	0.78	0.21	0.55	0.61
h:Energy, Array Field, NoConnect	kWh	0.0	2.0	0.0	0.0	3.0	0.0
3:Plant Performance Indices							
a:PV Array Energy Cabability	kWh	498.0	464.0	348.0	109.0	211.0	85.0
b:Array Utillization Factor	%	100.0	99.6	100.0	100.0	98.6	100.0
c:Array Energy Efficiency (Irrad.>50)	%	10.5	10.4	12.4	4.3	7.7	5.7
e:System Energy Efficiency DayAvg	%	65.4	61.3	62.1	31.9	56.3	53.3
f:Plant Availability	%	100.0	100.0	100.0	83.9	100.0	100.0
4:Battery Information							
a:DOD,% rated Ah, DayAvg	%	91.4	84.3	79.7	92.0	82.8	77.7
b:No cycles, DOD-Avg>5%	no	22	27	27	15	24	25
c:Cell Temperature, DayAvg	degree	27.0	26.8	26.7	23.7	23.6	23.6
f:Level electrolyte DayAvg	%	62.6	56.2	52.0	40.2	74.1	71.4
5:Operation and Maintenance Information							
a:Percent of total time DRO operational	%	100.0	100.0	100.0	83.9	100.0	100.0
c:Percent of total time Inverter operational	%	100.0	100.0	100.0	83.9	100.0	100.0
d:Number of failures and MTTR for major components							
1)number	no	0.0	0.0	0.0	5.0	0.0	0.0
2)MTTR	h						
6:Application Information							
a:Comsumer (Load) Energy, sum.	kWh	564.2	535.6	559.6	129.0	396.4	463.8
b:System consumption, sum.	kWh	96.7	96.7	93.6	81.1	93.6	96.7
c:Energy from Grid to PV plant, sum.	kWh	364.1	412.4	552.7	296.0	496.4	784.9

Table 6.3.1.c: Data 1989/1.

PV pilot plant:PV-house Bramming
Site manager:M.Jørgensen
Project manager:B.Mortensen

Date of report:890920
Prepared by:M.Jørgensen
Telephone:+4586293366 ext.4205
YEAR : 1989

Latitude (N): 56
Longitude (E): 9
Altitude (m): 30

PARAMETER	UNITS	JAN.	FEB.	MARCH	APRIL	MAY	JUNE
1.Solar/temperature							
a:Insolation Energy.Plane of array	kWh/m2	19.0	41.9	62.7	102.2	152.0	133.5
c:Irradiance.Plane DayAvg(24h)	W/m2	25.5	62.4	84.3	141.9	211.1	185.4
f:Temperature, back of PV-module DayAvg	degree	10.4	10.9	12.9	14.9	23.5	27.8
at 6 pm	degree	9.2	8.8	8.5	7.6	11.1	14.0
at 12	degree	13.7	17.4	20.6	26.1	40.9	47.0
at 6 am	degree	9.5	11.8	12.8	18.8	28.7	33.6
h:Temperature. Ambient DayAvg	degree	6.0	6.0	7.4	7.8	13.9	18.1
i:Temperature. Ambient DayLow	degree	-7.7	1.3	1.2	-2.0	5.7	6.3
2:Plant Output Information							
a:Energy, Array Field, Used	kWh	98.0	197.0	287.0	463.0	635.0	641.0
b:Energy, Inverter	kWh	463.9	469.9	509.7	492.0	453.7	390.4
c:Power, Array DayAvg, used	kW	0.1	0.3	0.4	0.6	0.9	0.9
e:Power, Inverter DayAvg	kW	0.6	0.7	0.7	0.7	0.6	0.5
h:Energy, Array Field, NoConnect	kWh	0.0	1.0	1.0	2.0	28.0	37.0
3:Plant Performance Indices							
a:PV Array Energy Cabability	kWh	98.0	198.0	288.0	465.0	663.0	678.0
b:Array Utillization Factor	%	100.0	99.5	99.7	99.6	95.8	94.5
c:Array Energy Efficiency (Irrad.>50)	%	5.5	7.0	8.4	8.8	9.4	13.1
e:System Energy Efficiency DayAvg	%	58.0	58.0	59.9	61.7	57.2	54.1
f:Plant Availability	%	100.0	100.0	100.0	100.0	96.8	100.0
4:Battery Information							
a:DOD,% rated Ah, DayAvg	%	79.7	78.0	79.2	84.2	85.4	86.0
b:No cycles, DOD-Avg>5%	no	23.0	21.0	28.0	22.0	18.0	18.0
c:Cell Temperature, DayAvg	degree	23.4	23.6	23.8	23.9	28.0	30.3
f:Level electrolyte DayAvg	%	63.6	57.7	52.5	46.3	71.3	68.3
5:Operation and Maintenance Information							
a:Percent of total time DRO operational	%	100.0	100.0	100.0	100.0	96.8	100.0
c:Percent of total time Inverter operational	%	100.0	100.0	100.0	100.0	96.8	100.0
d:Number of failures and MTTR for major components							
1)number	no	0.0	0.0	0.0	0.0	1.0	0.0
2)MTTR	h						
6:Application Information							
a:Consumer (Load) Energy, sum.	kWh	463.9	469.9	509.7	492.0	453.7	390.4
b:System consumption, sum.	kWh	96.7	87.4	96.7	93.6	93.6	93.6
c:Energy from Grid to PV plant, sum.	kWh	701.2	612.9	563.8	333.9	158.0	80.7

Table 6.3.1.d: Data 1989/2.

PARAMETER	YEAR : 1989 UNITS	JULY	AUG.	SEP.
1.Solar/temperature				
a:Insolation Energy.Plane of array	kWh/m2	107.0	97.0	95.7
c:Irradiance.Plane DayAvg(24h)	W/m2	143.8	130.4	132.9
f:Temperature, back of PV-module DayAvg	degree	27.4	24.4	23.3
at 6 pm	degree	17.8	17.5	15.3
at 12	degree	40.3	36.2	34.6
at 6 am	degree	32.4	27.7	28.3
h:Temperature. Ambient DayAvg	degree	18.8	17.3	16.2
i:Temperature. Ambient DayLow	degree	10.4	9.7	7.8
2:Plant Output Information				
a:Energy, Array Field, Used	kWh	533.0	475.0	443.0
b:Energy, Inverter	kWh	527.4	528.6	519.1
c:Power, Array DayAvg,used	kW	0.7	0.6	0.6
e:Power, Inverter DayAvg	kW	0.7	0.7	0.7
h:Energy, Array Field, NoConnect	kWh	2.0	10.0	0.0
3:Plant Performance Indices				
a:PV Array Energy Cabability	kWh	535.0	485.0	443.0
b:Array Utillization Factor	%	99.6	97.9	100.0
c:Array Energy Efficiency (Irrad.>50)	%	11.3	9.6	9.3
e:System Energy Efficiency DayAvg	%	57.5	59.5	61.0
f:Plant Availability	%	100.0	100.0	100.0
4:Battery Information				
a:DOD,% rated Ah, DayAvg	%	79.6	78.3	80.5
b:No cycles, DOD-Avg>5%	no	18.0	25.0	26.0
c:Cell Temperature, DayAvg	degree	28.2	43.1	25.4
f:Level electrolyte DayAvg	%	58.0	45.1	90.8
5:Operation and Maintenance Information				
a:Percent of total time DRO operational	%	100.0	100.0	100.0
c:Percent of total time Inverter operational	%	100.0	100.0	100.0
d:Number of failures and MTTR for major components				
1)number	no	0.0	0.0	0.0
2)MTTR	h			
6:Application Information				
a:Comsumer (Load) Energy, sum.	kWh	527.4	528.6	519.1
b:System consumption, sum.	kWh	96.7	96.7	93.6
c:Energy from Grid to PV plant, sum.	kWh	384.2	413.3	407.5

6.3.2. On the next page an energy flow diagram is shown.

The diagram is general for the entire installation but the numerical values are based on data from the month of June 1989.

Data are produced as: (letters refer to the designations of the figure):

- A (insolated solar energy): 6942 kWh. This figure results as the number-_of_panels*actual_area_of_the_panel*the_irradiation. 9*29*0.2
- E (energy supplied by the rectifier): 80 kWh. This figure is measured directly.
- B (energy from disconnected solar strings): 37 kWh. This figure is calculated by the DRO directly.
- D (utilized energy from the solar arrays): 641 kWh. This figure is measured directly.
- C (PV-loss): "A"-"B"-"D" = 6264 kWh.
- F (total energy to the system): 721 kWh. Sum of "E" + "D".
- M (applied energy from the inverter): 390 kWh. Measured directly.
- N (inverter loss): 108 kWh. The load known indicates that the loss in the inverter is approx. 3.6 kWh day and night totalling 3.6*30 = 108 kWh.
- K (dc-consumption of the inverter): Is "T"+"S" = 390 + 108 = 498 kWh.
- L (own consumption of the system): This is 130 watt on an average, totalling 130*24*30 = 94 kWh.
- I (loss in battery): 129 kWh. This figure is calculated as: F-K-L.
- J (from the battery): 504 kWh. Calculated as: 14% discharged on an average. Capacity 120 kWh. 120*0.14*30 = 504 kWh.
- G (energy supplied to the battery storage): "J" + "I" = 633 kWH
- H (energy around the battery): 721 - 633 = 88 kWh

Although some of the values are estimated values the figure gives a survey of the energy flow in the system.

The above-mentioned main figures give a system efficiency for the period of:

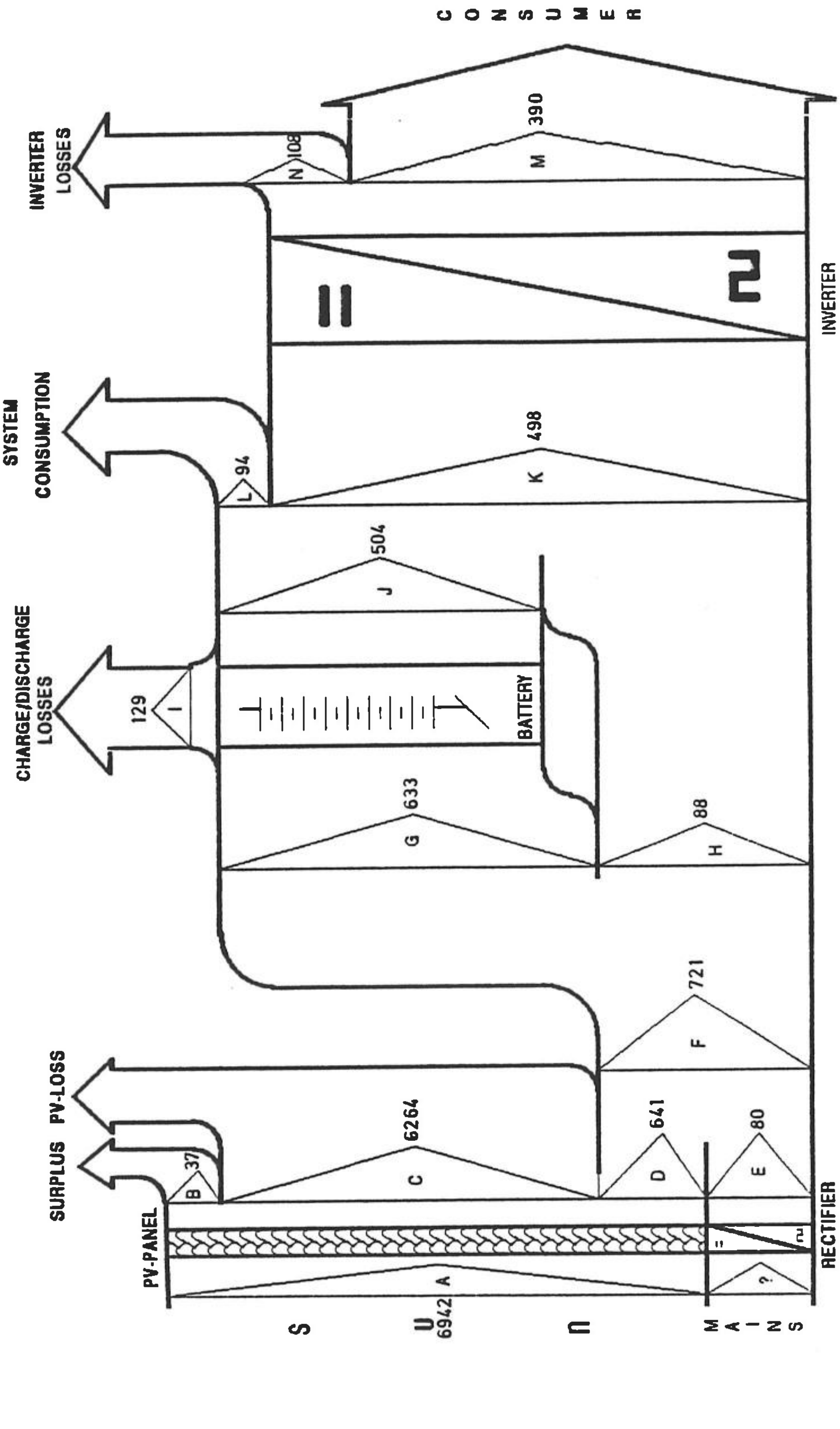
<u>Energy out</u> Energy in	$\frac{390}{6942 + 80}$	approx. 5.5%

If the losses in the solar arrays is left out as well as the amount of energy which has been disconnected in the period as inapplicable owing to high battery voltage the system efficiency is as follows:

<u>Energy out</u> Energy in	$\frac{390}{641 + 80}$	approx. 54%

The battery efficiency for the period has been:
504/633*100 = 79%.

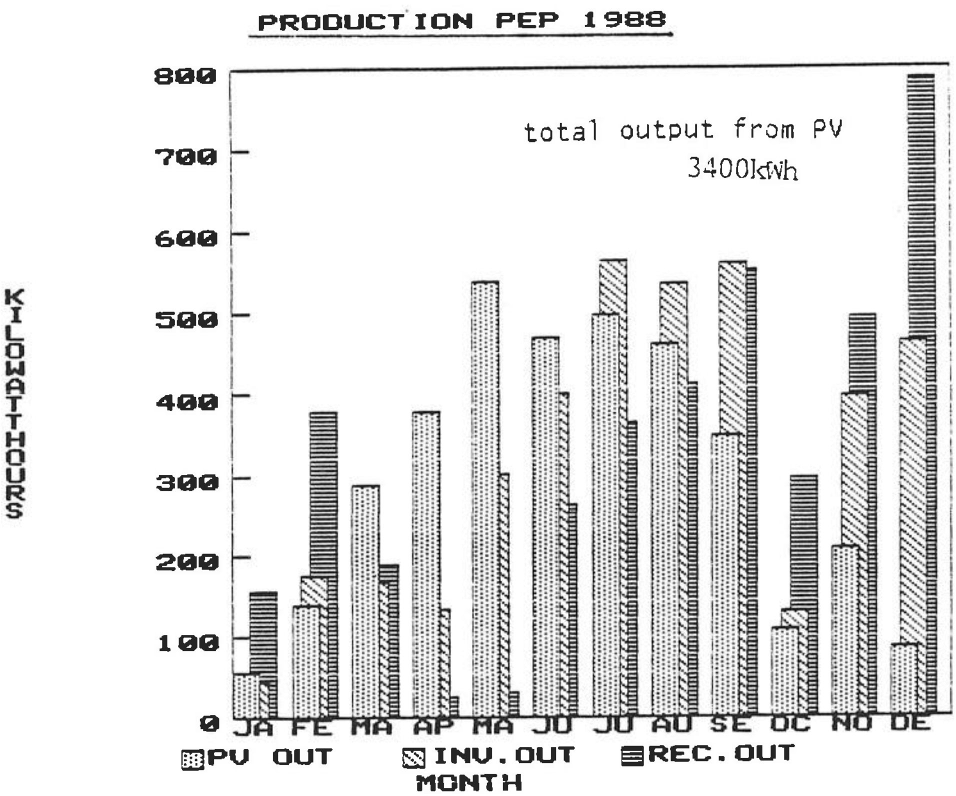
Fig 6.3.2.a: Energy flow diagram for June 1989.



6.3.3 Data from 1988-89 shown in curve.

The following pages show data on a form that are not immediately accessible in the survey reports shown above.

Fig.6.3.3.a: The curves show the production from PV, inverter output and rectifier output for 1988 and 1989, respectively.



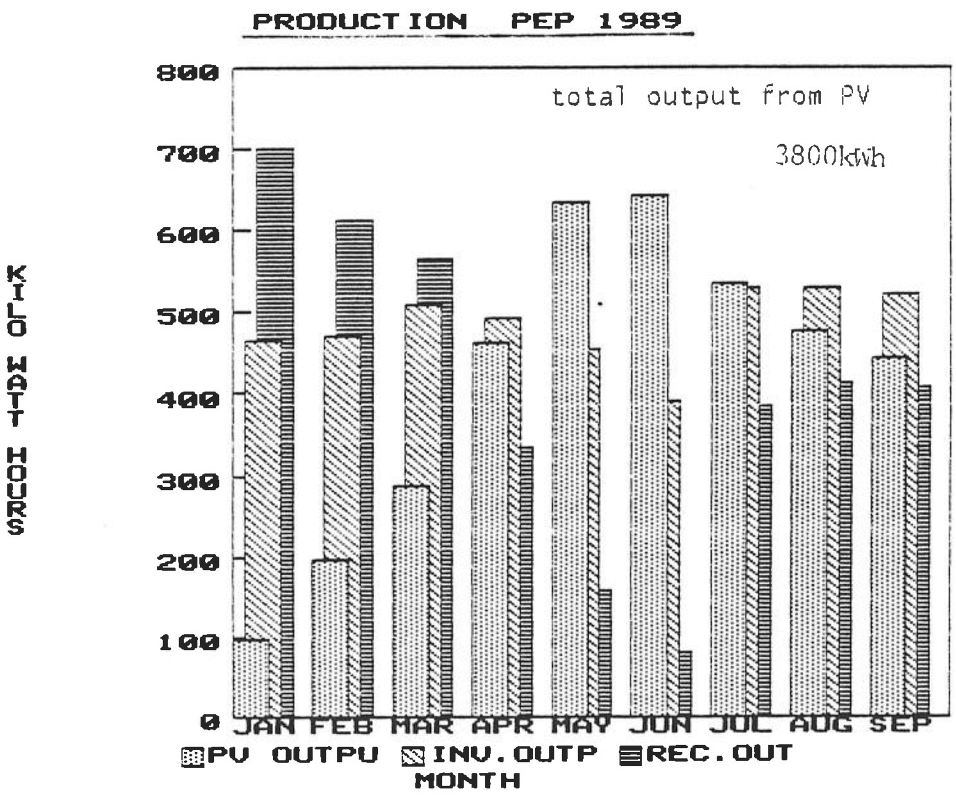
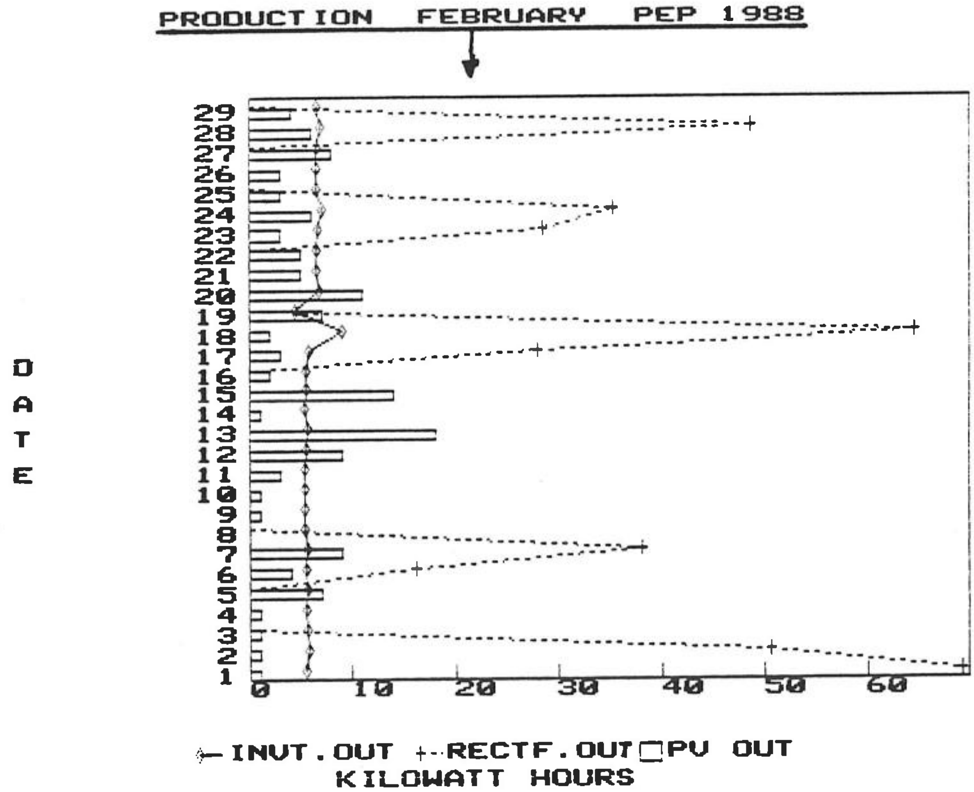


Fig. 6.3.3.b: The curves show the same data as on the previous page. However, a summer and winter month in 1988 has been selected showing a higher degree of details.



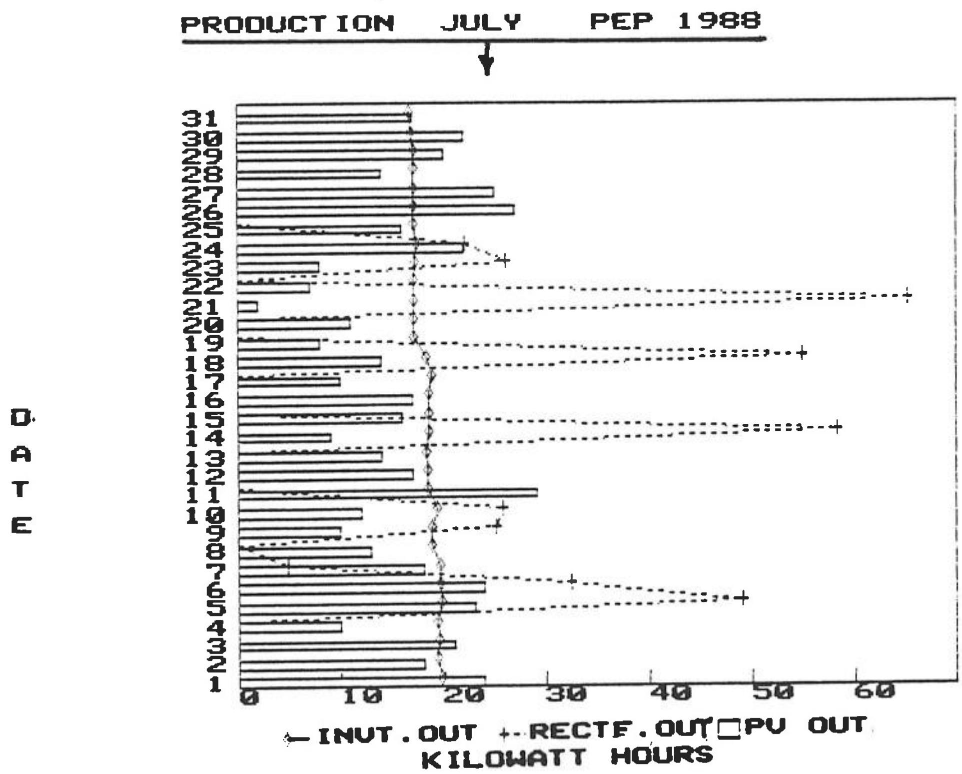
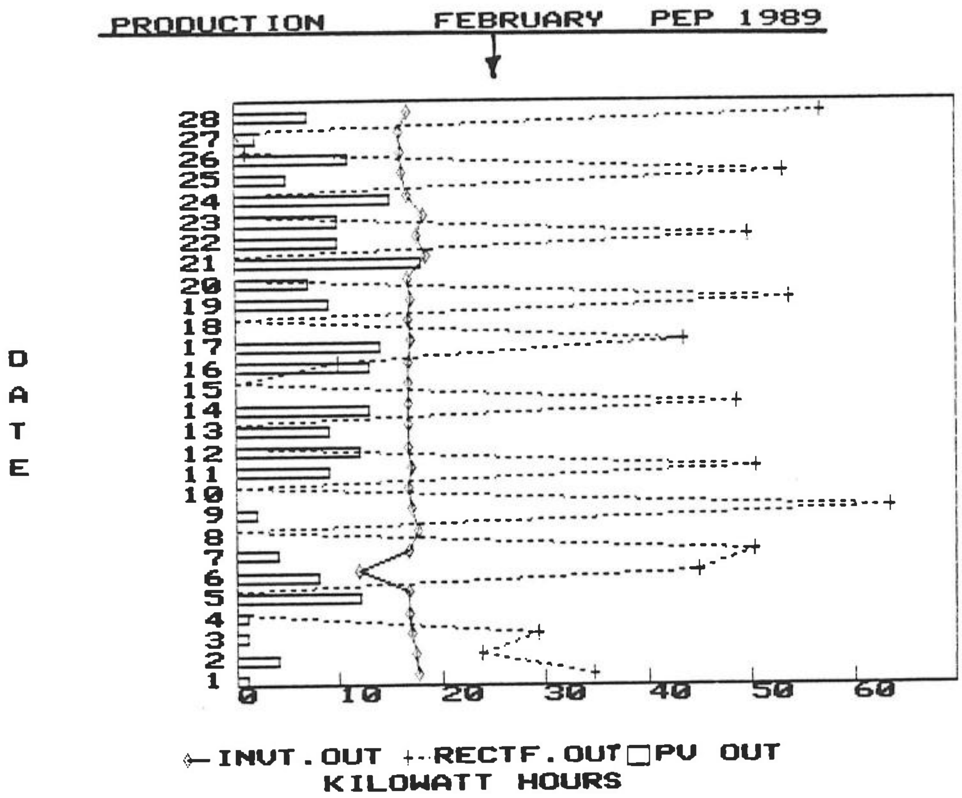


Fig. 6.3.3.c: As previous figure however for 1989.



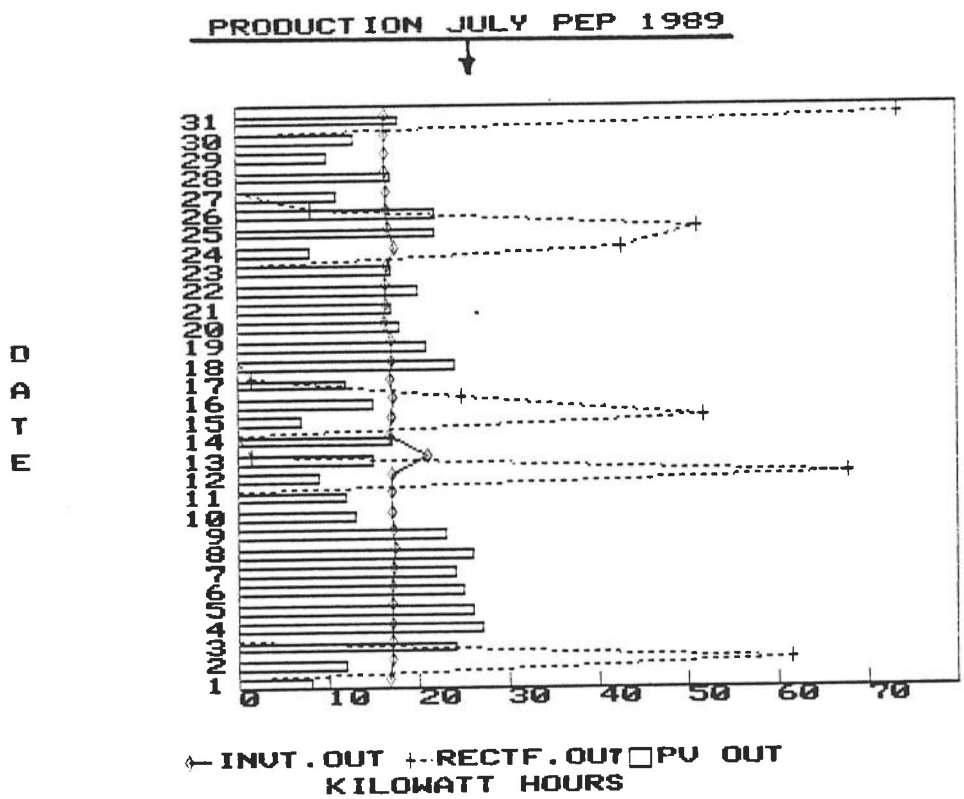
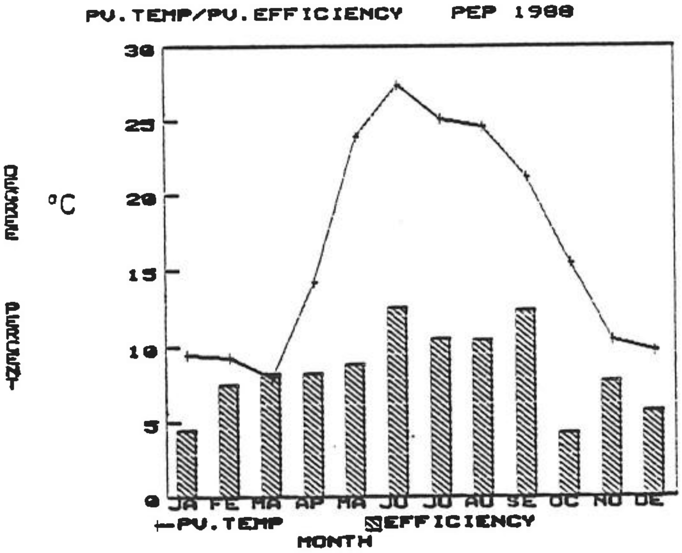
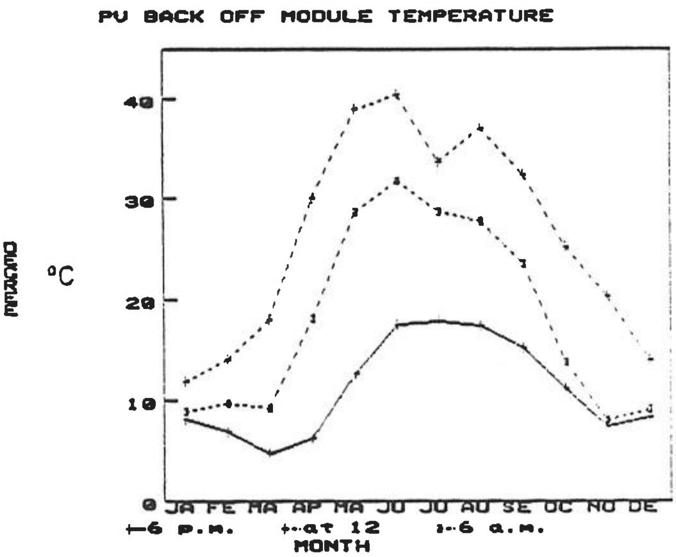


Fig. 6.3.3.d: The relation between the PV-temperature and the efficiency for 1988 appears from the curves. Furthermore, the temperature on the PV-modules is shown for three different times of the day. The last curve shows the outdoor temperature for 1988.





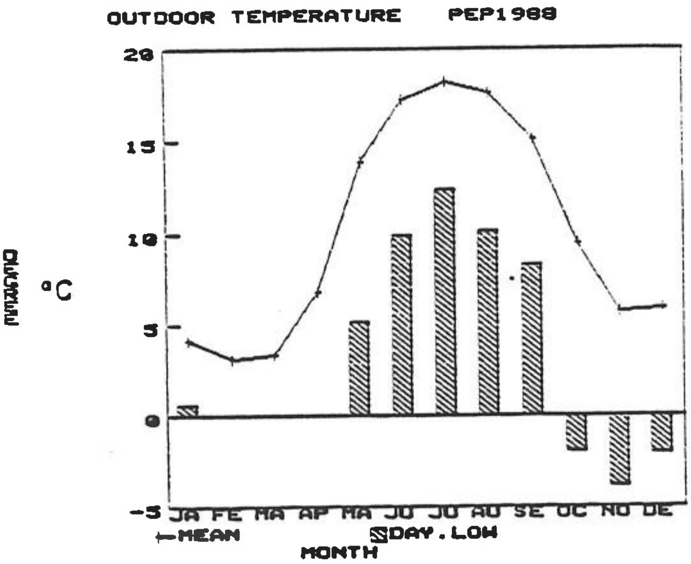
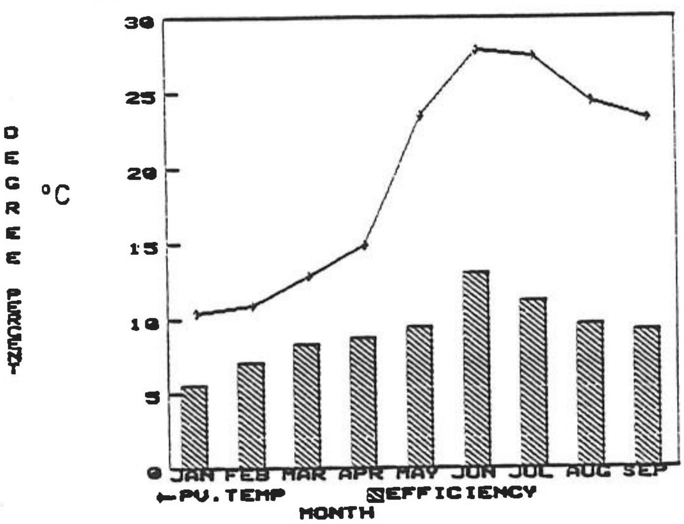
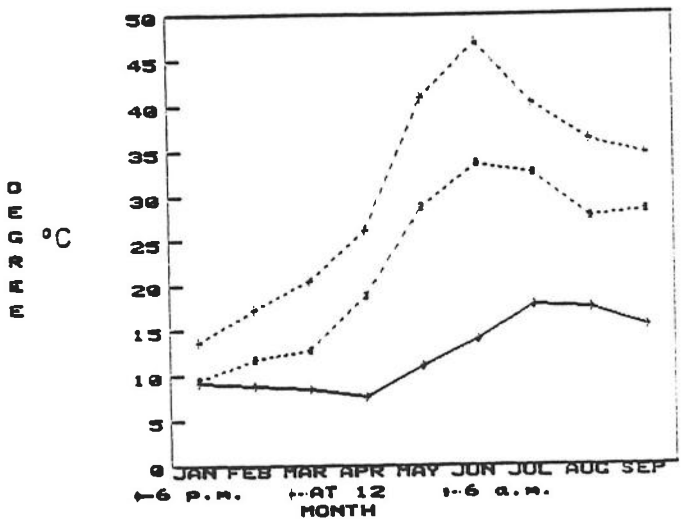


Fig. 6.3.3.e: The relation between the PV-temperature and the efficiency for 1989 appears from the curves. Furthermore, the temperature on the PV-modules is shown for three different times of the day. The last curve shows the outdoor temperature for 1989.

PV.TEMP/PV.EFFICIENCY PEP 1989



PV BACK OF MODULE TEMPERATURE PEP 1989



OUTDOOR TEMPERATURE PEP 1989

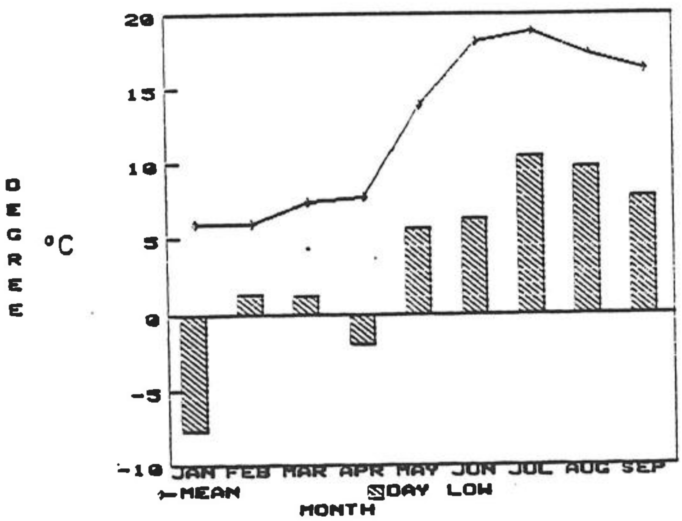
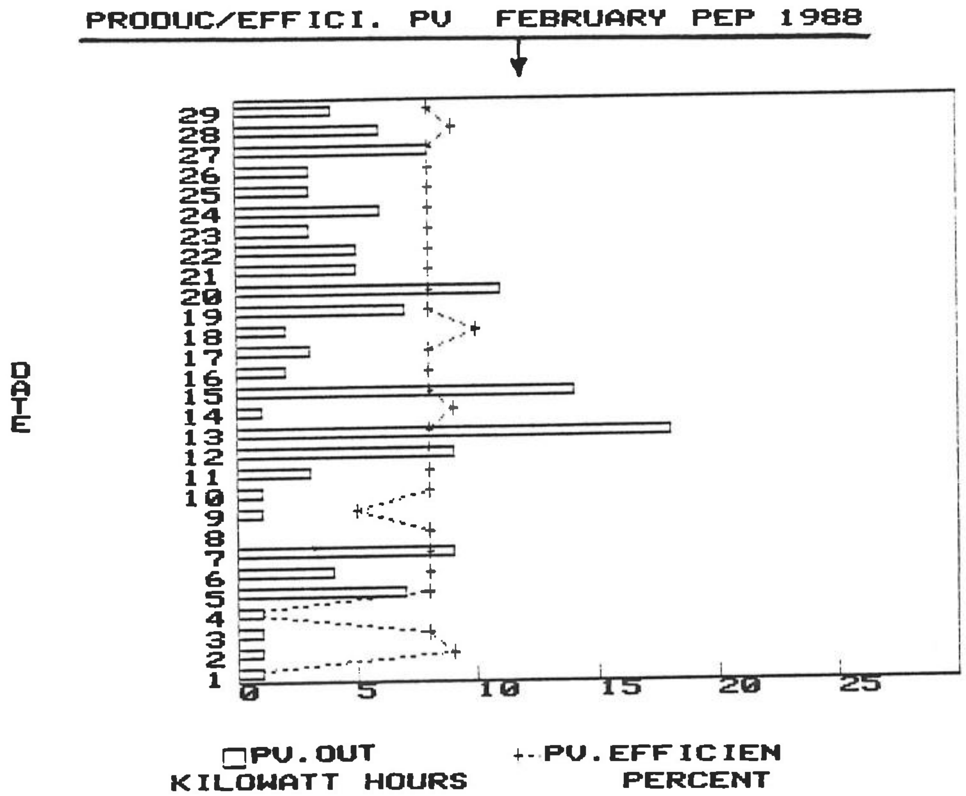


Fig. 6.3.3.f: The curves show the relation between the PV-production and the efficiency in two selected months in 1988.



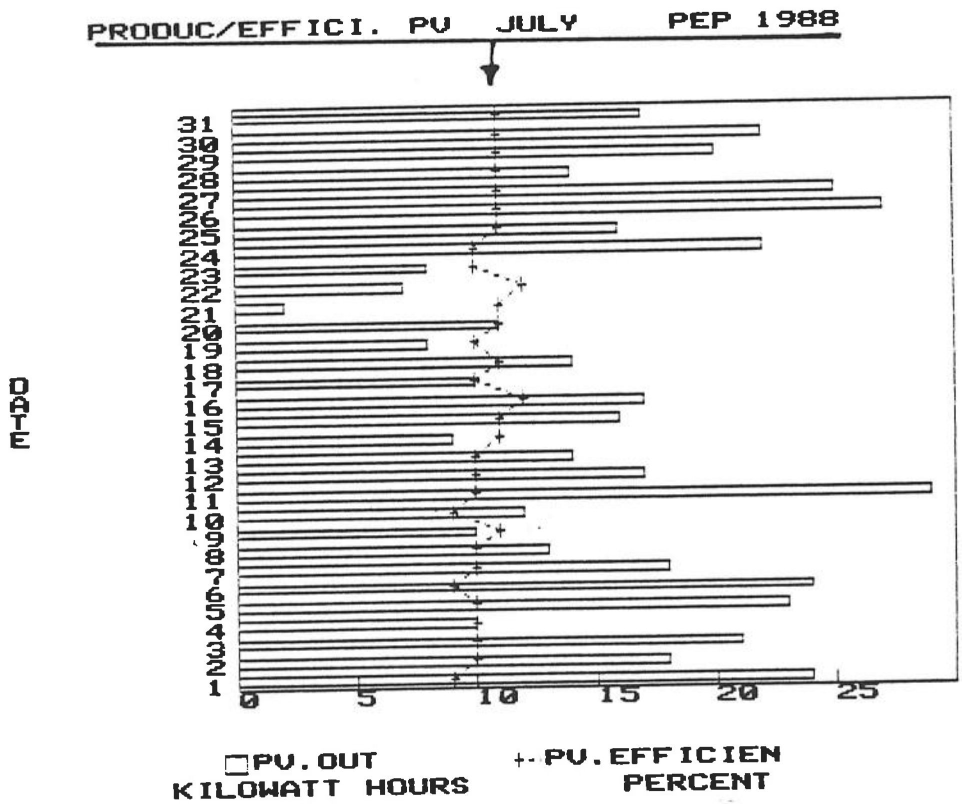
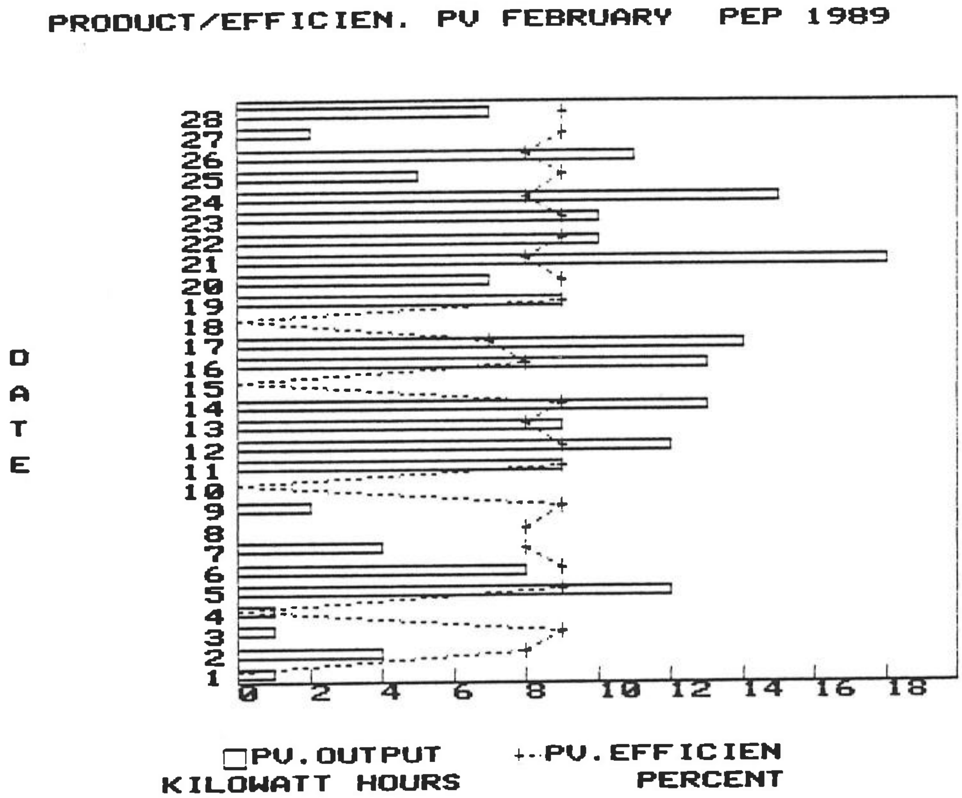


Fig. 6.3.3.g: The curves show the relation between the PV-production and the efficiency in two selected months in 1989.



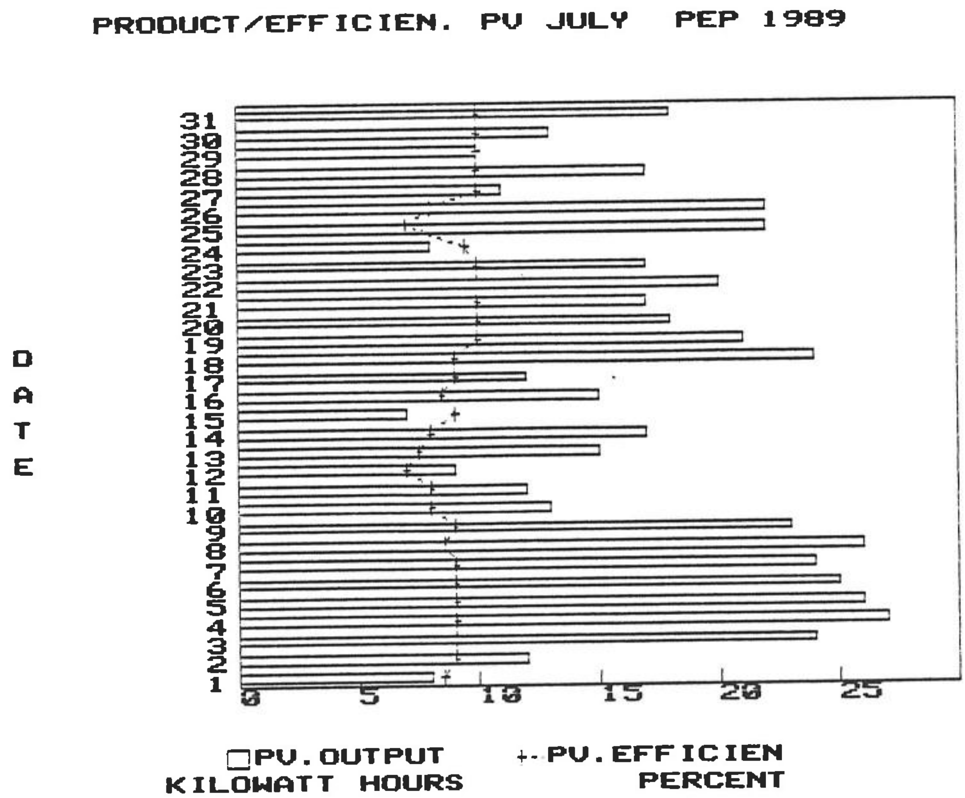
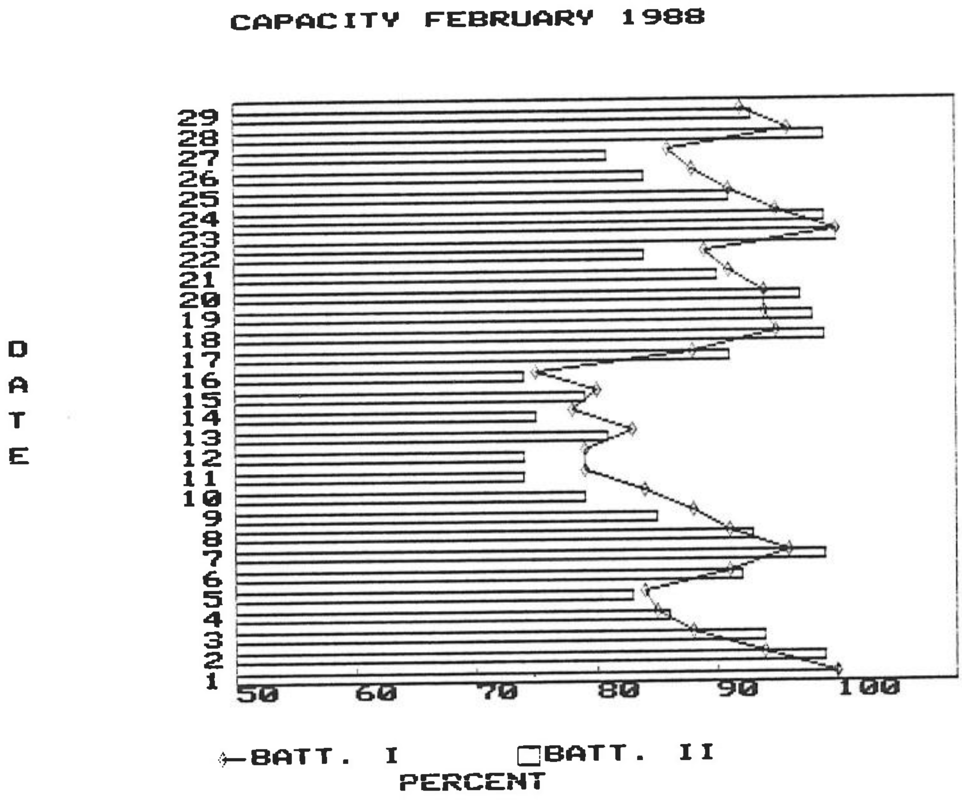


Fig. 6.3.3.h: The curves show the State of Charge of the batteries on the individual days in two selected months in 1988.



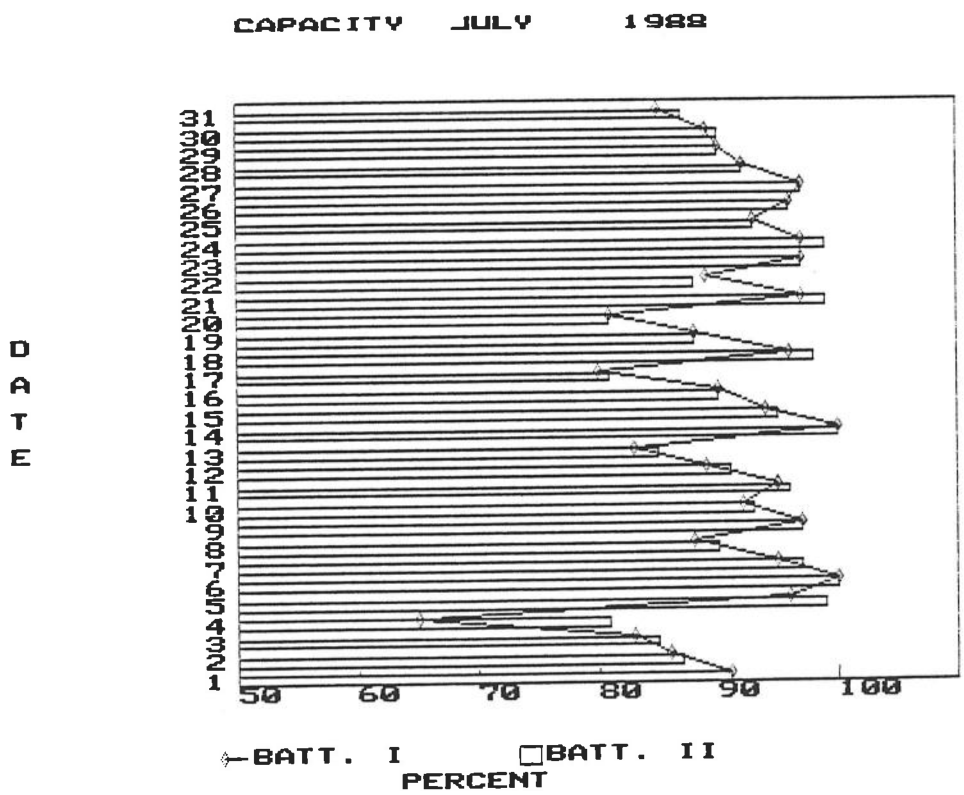
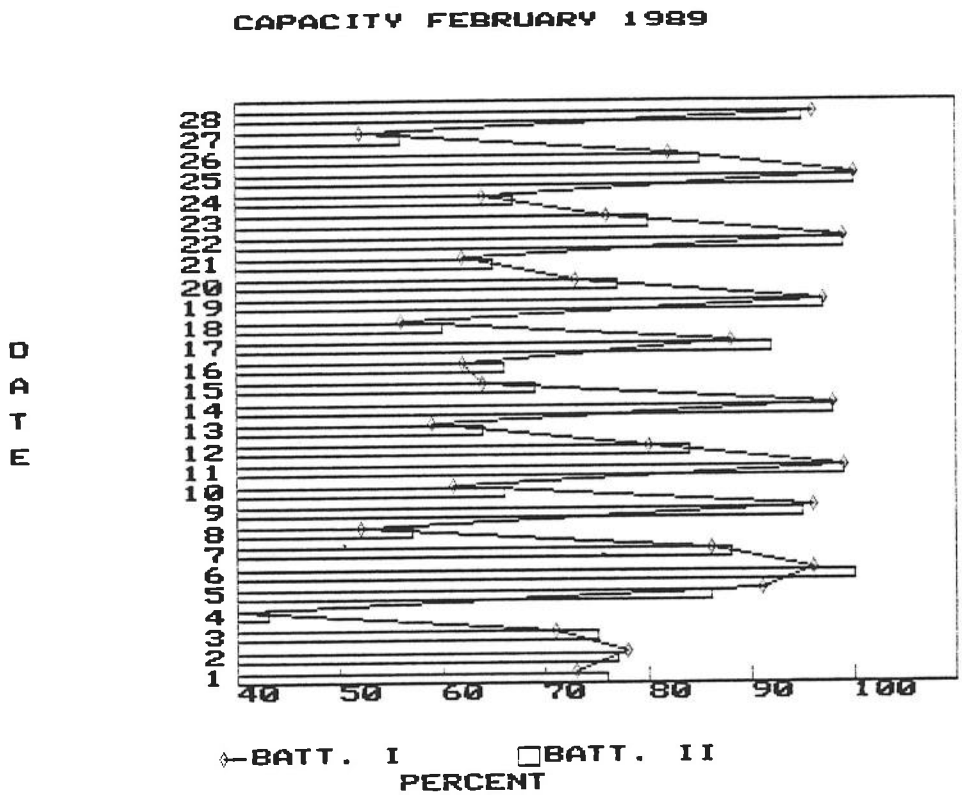
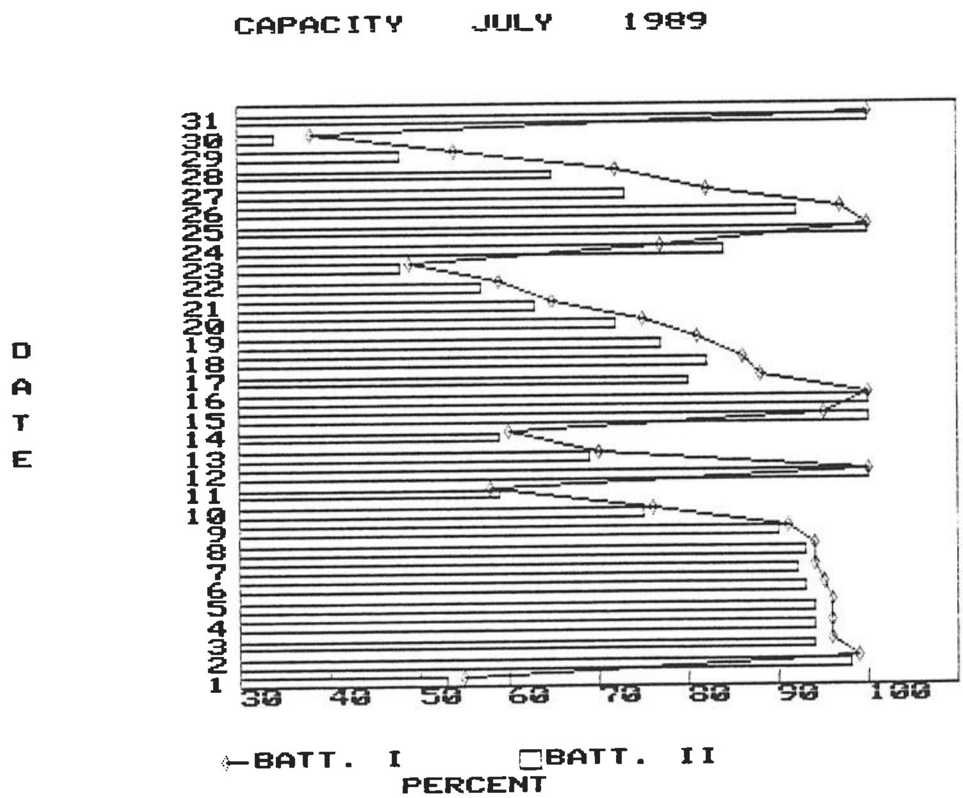


Fig. 6.3.3.i: The curves show the State of Charge of the batteries on the individual days in two selected months in 1989.





6.4. Short-time measurements

In order to have the operational conditions of the plant determined with very small time intervals in a random period between two chargings from the rectifier, the plant has been logged for relevant data at intervals of 15 minutes.

In this case the period between the two chargings was from 28.08.89 at 16.20 where the rectifier stops with a 100% charged battery and the 01.09.89 at 02.20 where the rectifier stops again with a fully charged battery.

Because the battery has the same charging condition it is now possible to make calculations on the energies which were in the system.

Fig.6.4.a: Test point diagram

```
      / IRRADIANCE
     / TEMPERATURE
    /
   / ------> PV.OUTPUT   ------>| S |------> DC.LOAD -->inv.output
  /                             | Y |
 /           RECTIFIER   ------>| S |<-----> BATTERY 1
                                | T |
             DRO, ect    <------| E |<-----> BATTERY 2
                                | M |
                                  *
                                  *dc Voltage
```

6.4.1. Main figures

In the period between the two chargings the following main figures are:

Time total	: 82 hours
PV output	: 38.5 kWh
Rectifier output	: 60.5 kWh
Dc load	: 82.5 kWh
Battery storage in	: 56.0 kWh
Battery storage out	: 48.0 kWh
Inverter output	: 64.5 kWh
Solar energy total	:425 kWh
Dc-voltage mean	:227 volt

On the basis of these figures the following can be derived for the period:

For supply of the DRO-4, transmission loss, etc:
38.5 + 60.5 + 48.0 - 82.5 - 56.0 = 8.5 kWh
which results in a consumption of 104 watt on an average.

The watt hour efficiency of the battery in the period was:
48/56 * 100 = 86%
which is a little on the large side of what was expected.

The efficiency of the inverter in the period was:
64.5/82.5*100 = 78%.

Normally the efficiency of the inverter, when this is loaded, is approx. 93% which will appear from the next pages.

Besides, the load pattern for the last couple of years appears from these pages. It should be noted that the rectifier has not been turned on in the selected time periods.

The efficiency of the system in the period is calculated as:

(inverter output/(PV + rectifier output)%
(64.5 / (38.5 + 60.5))% = 65%

which must be considered to be a little above the average for the month.

Fig. 6.4.1.a: The curve shows the sun irradiance for day 1 and day 2, respectively.

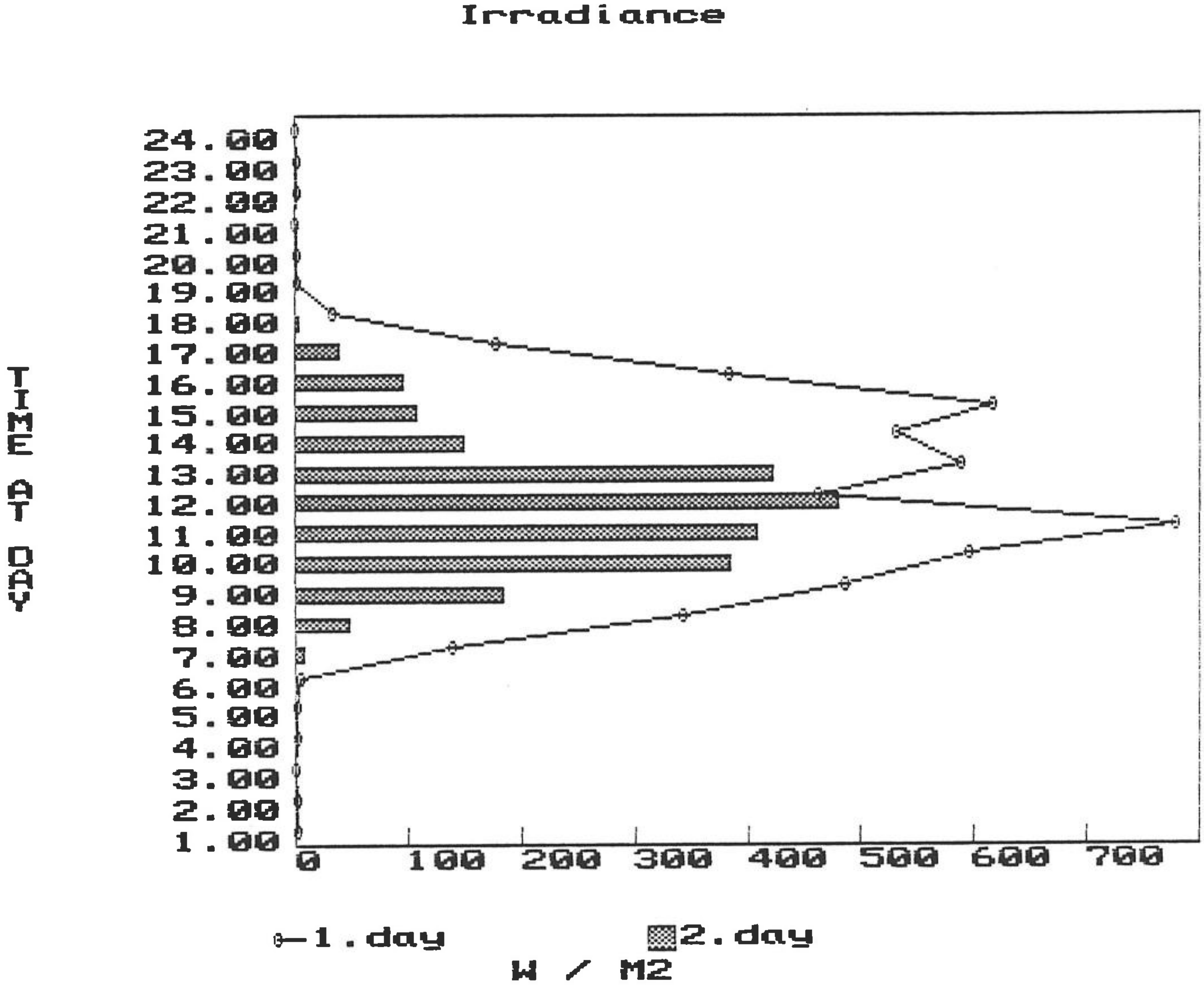
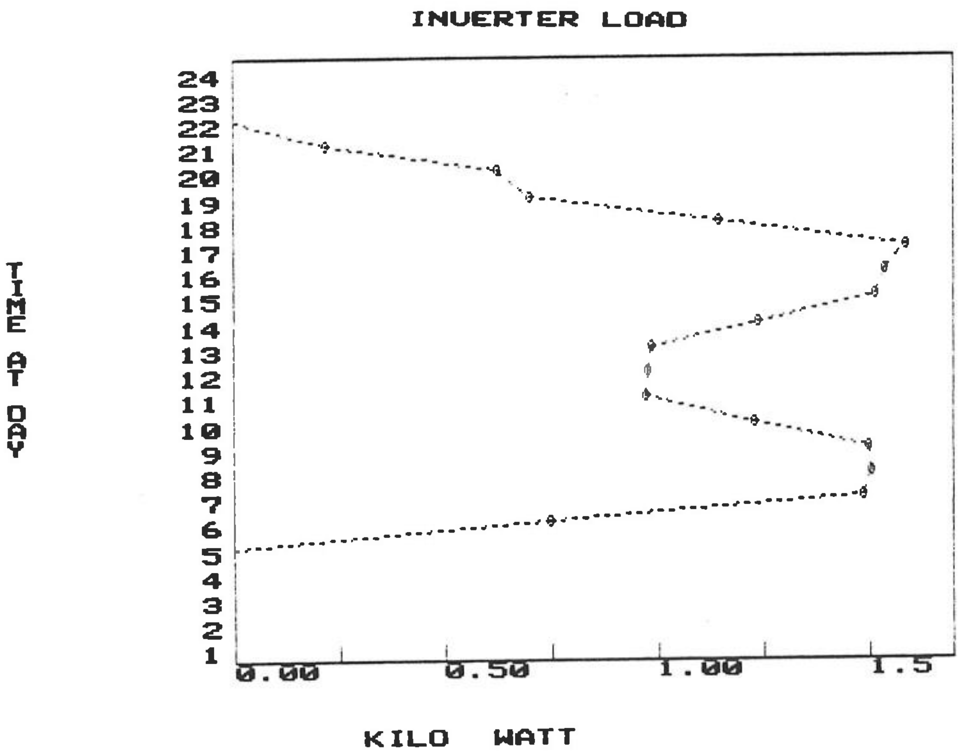


Fig. 6.4.1.b: The curves show the typical load of the plant for 24 hours and the efficiency of the inverter for the same period.



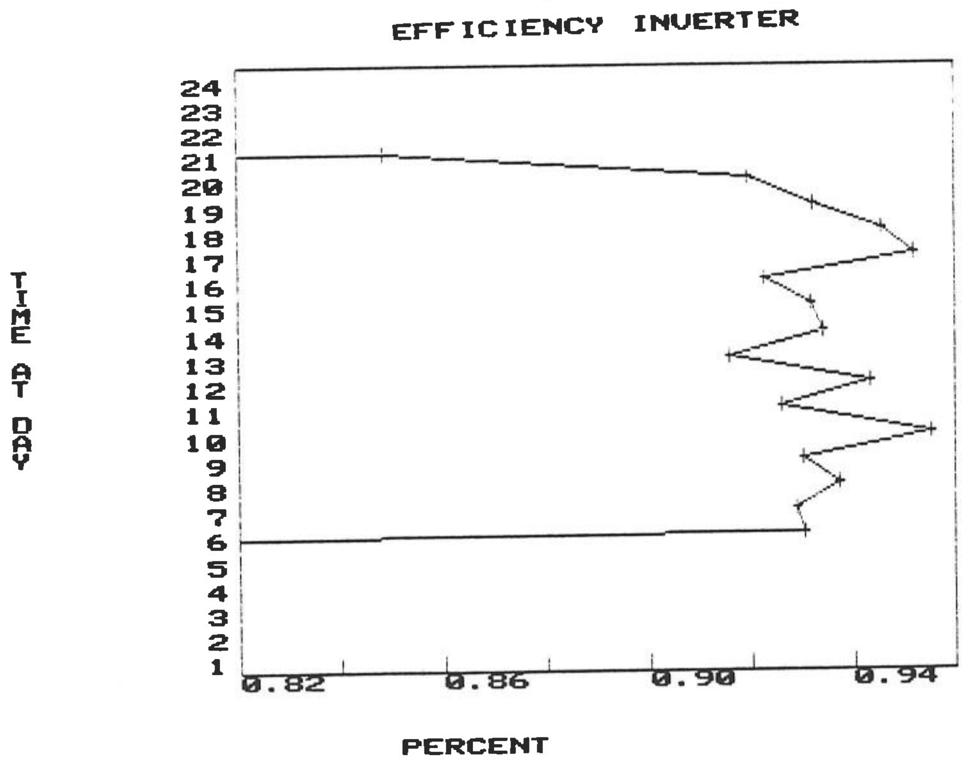
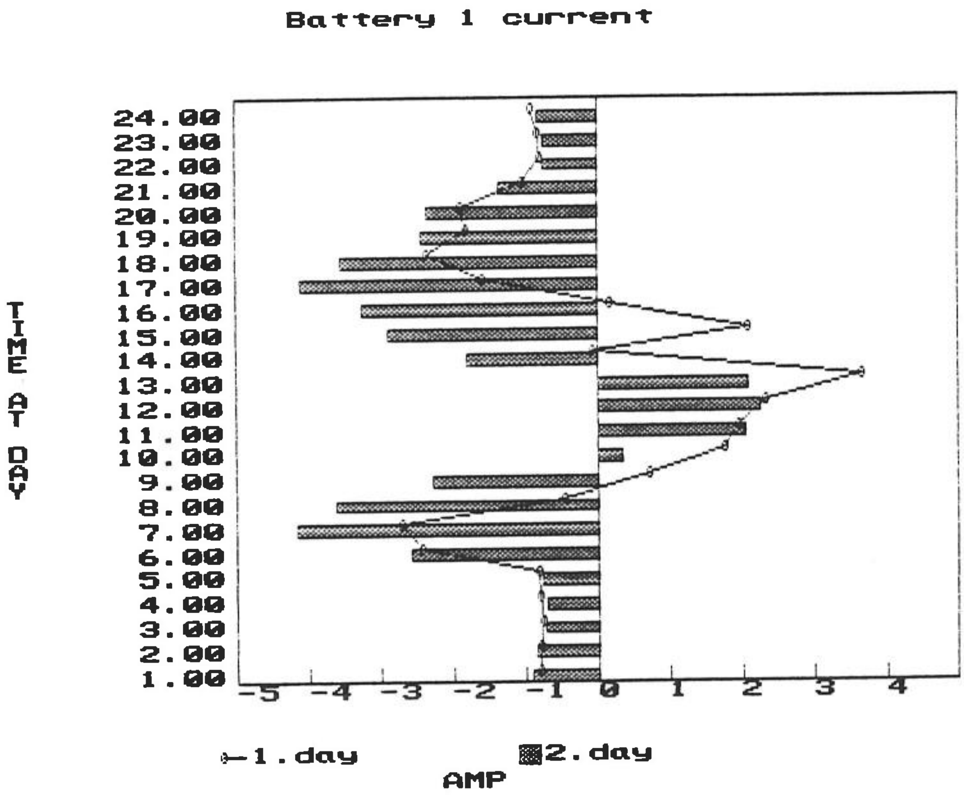


Fig. 6.4.1.c: The curves show the battery current during the selected days.



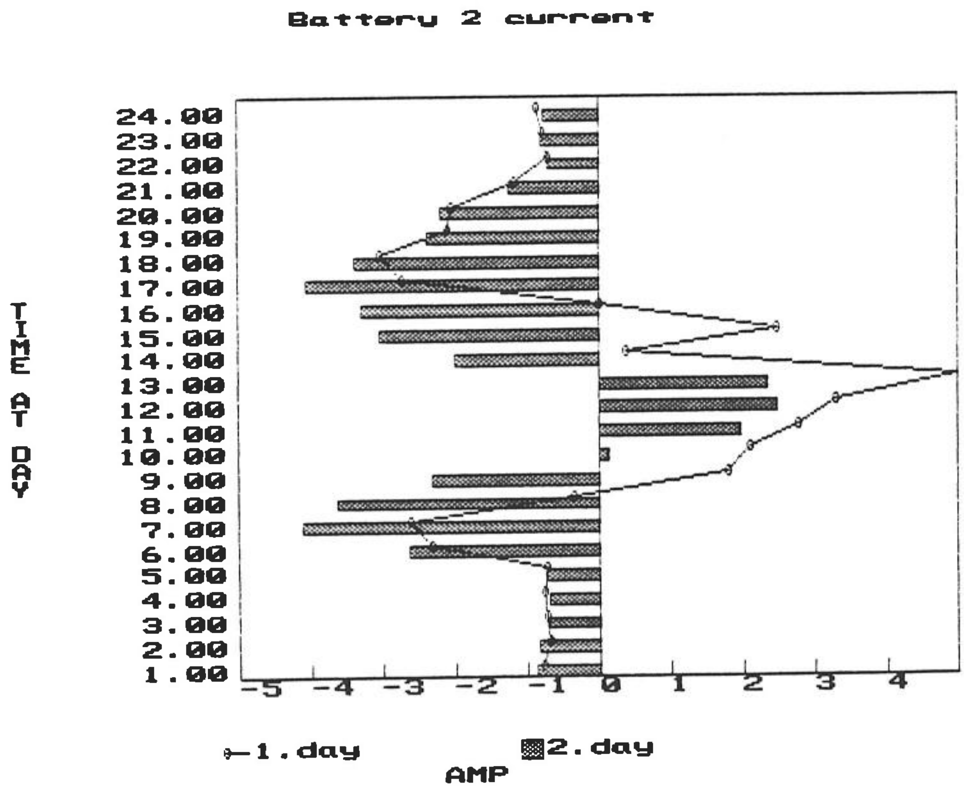
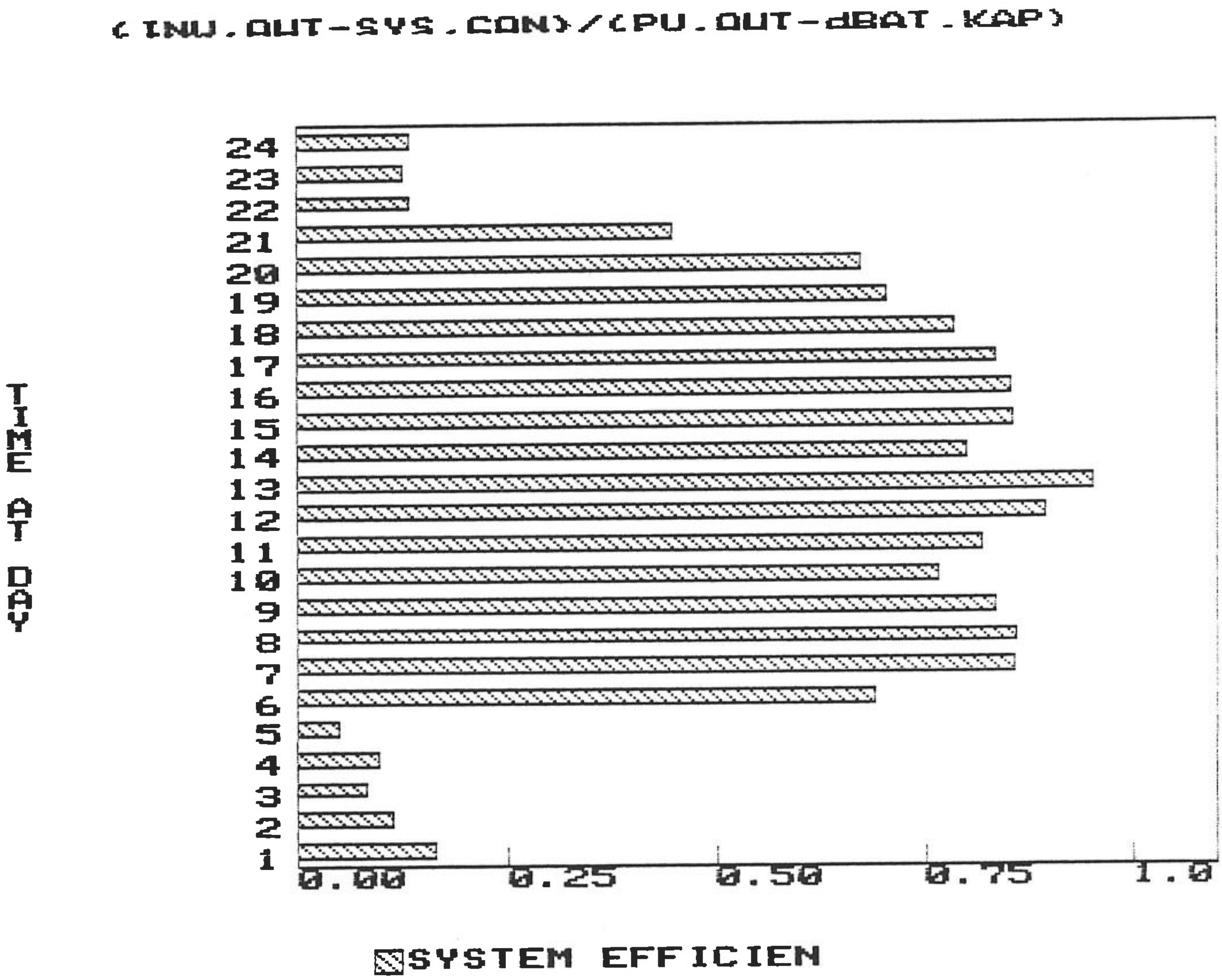


Fig. 6.4.1.d: The curve shows the system efficiency on an average for 24 hours. This is calculated as:
(inverter out - system consumption)/(PV out - increase of capacity)



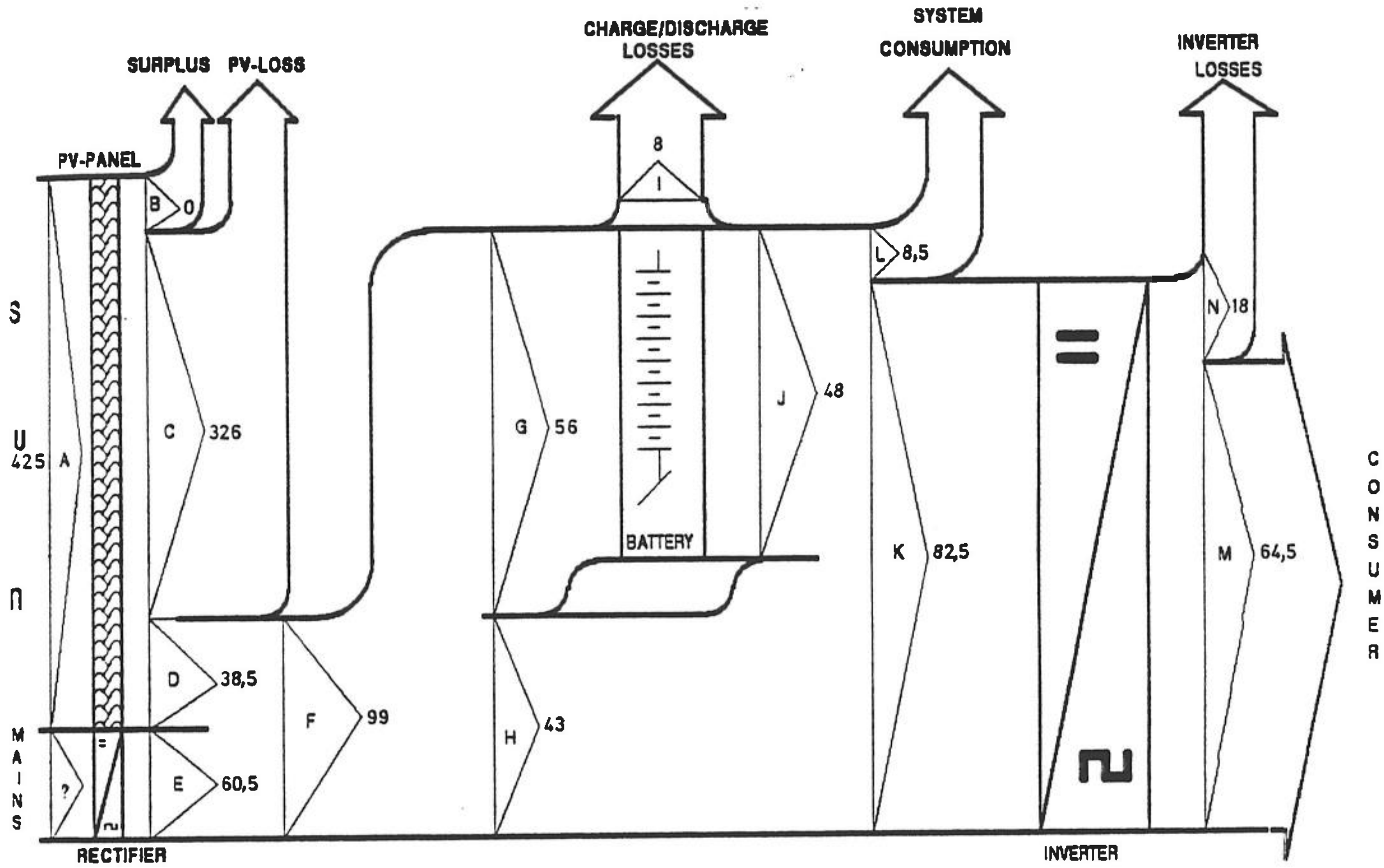
<u>Energy flow diagram</u>

Unlike previous flow diagrams of the same type several of the parameters in this one are known because of frequent measurements.

For example: "G" (energy to battery) 56 kWh
"J" (energy from battery) 48 kWh

This makes it possible to calculate "I" (the loss at charging and discharging) as G - J = 56 - 48 = 8 kWh.
Furthermore, the dc-load ("K) is registered which enables calculation of inverter load "N" and indirectly the own consumption "L" of the system.

Fig. 6.4.1.e: Energy flow diagram for the previously mentioned 82 hours.



6.4.2. Selected periods

On the following pages two days have been selected. In these two days the

1st day, time period from 07.00 to 14.30 in the afternoon
2nd day, time period from 07.10 to 14.30 in the afternoon

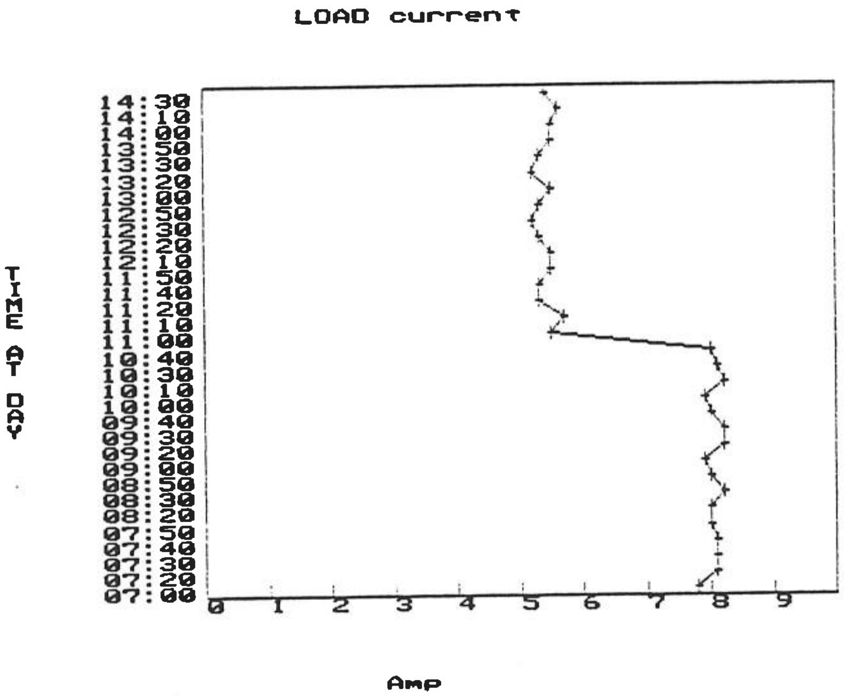
have been selected for further analysis.

The curves illustrate that the load and the energy flow are very fluctuating during the day.

It should be noted that as the various analog channels measure with various frequency (10 secs and 60 secs) there is not necessarily complete time accordance between the individual measuring values of the curves for the same time. (The scan rate is noted in parenthesis at the individual measuring).

Fig. 6.4.2.a:

LOAD current: (10) The curves show the dc load measured on a shunt in the input of the inverter. The reason for the minor fluctuations may be that the own consumption depends on whether the disc drive is in operation or not at the moment of measuring. Furthermore, the change at 11.00 is seen from a load of approx 1.5 kW to 1.0 kW.



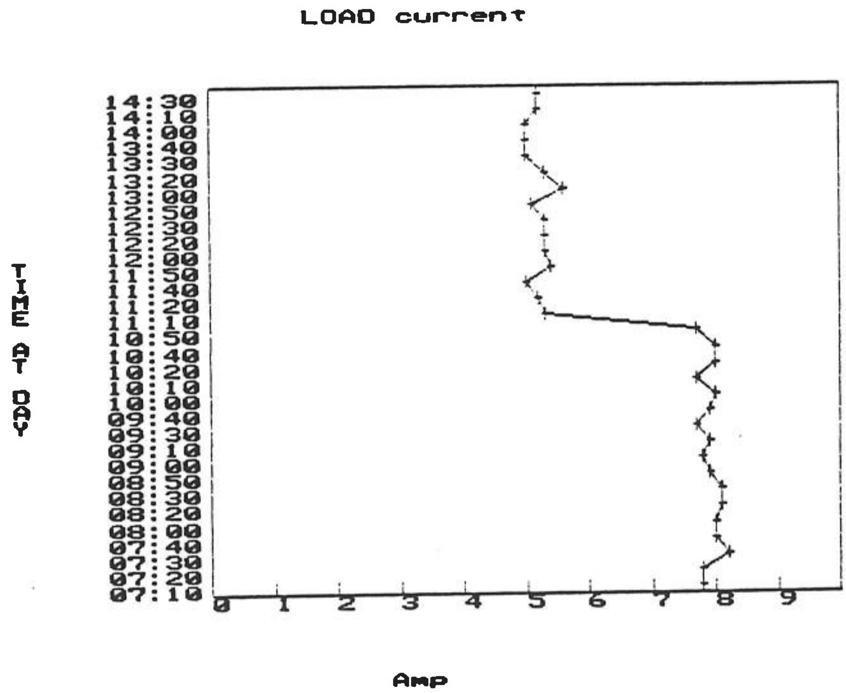
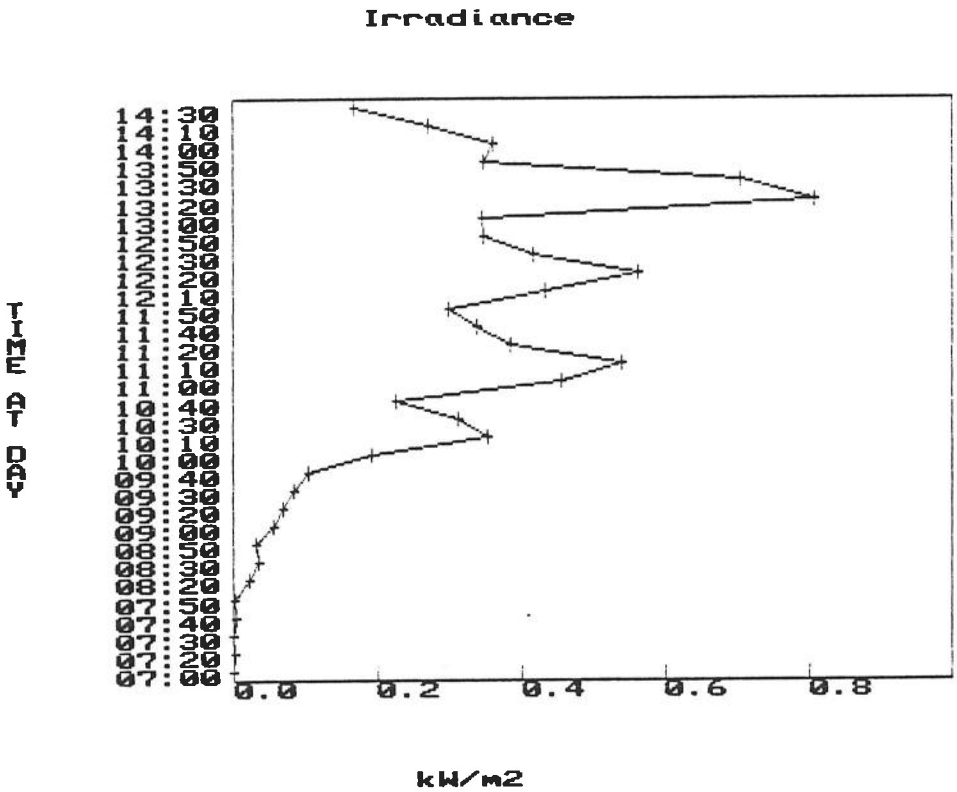


Fig. 6.4.2.b:

Irradiance:(60) The curves show the sun irradiance at various times of the day. The measurements are instantaneous and no kind of averaging is made.



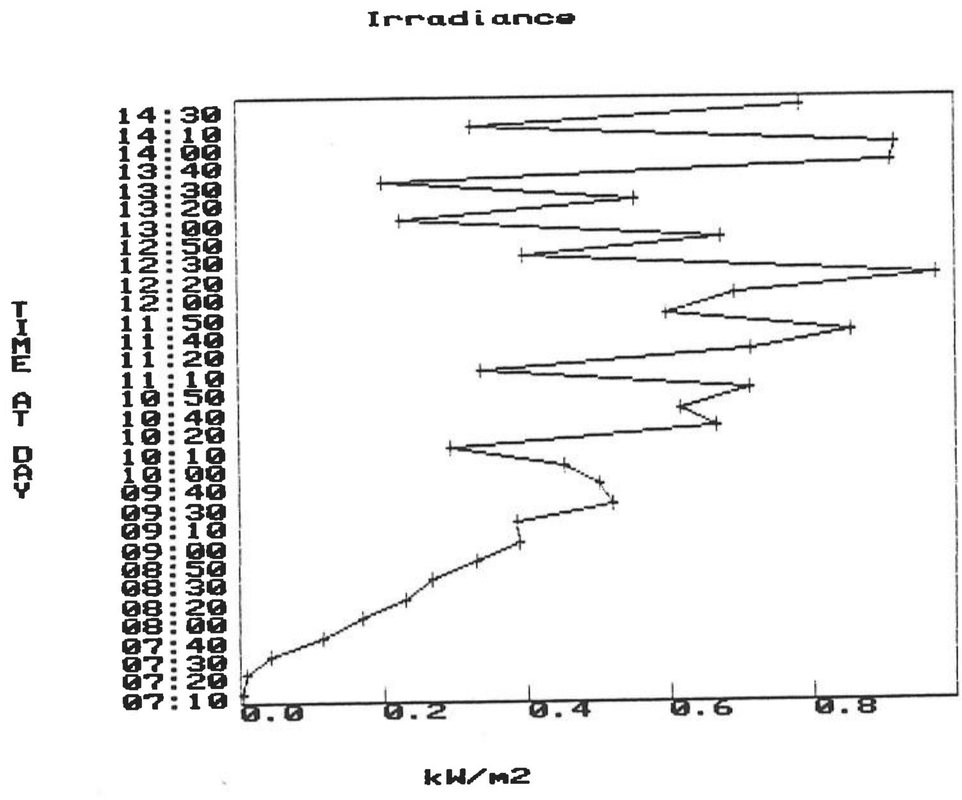
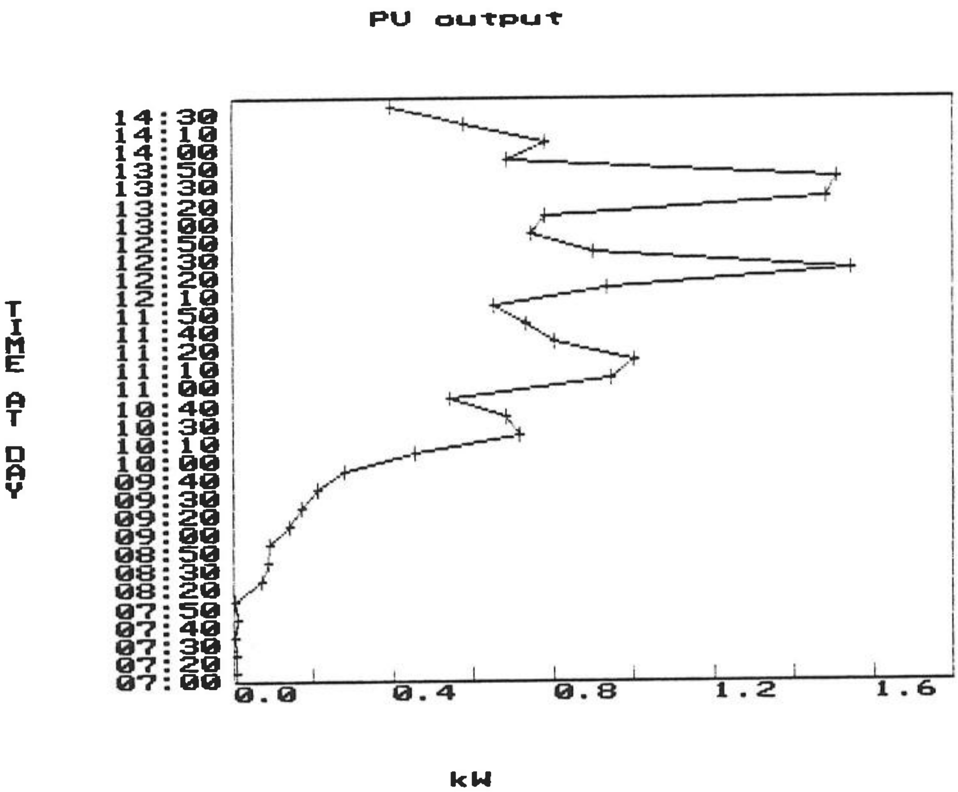


Fig. 6.4.2.c:

PV-output: (60) The curves show the output from the array during the various irradiation intensities.



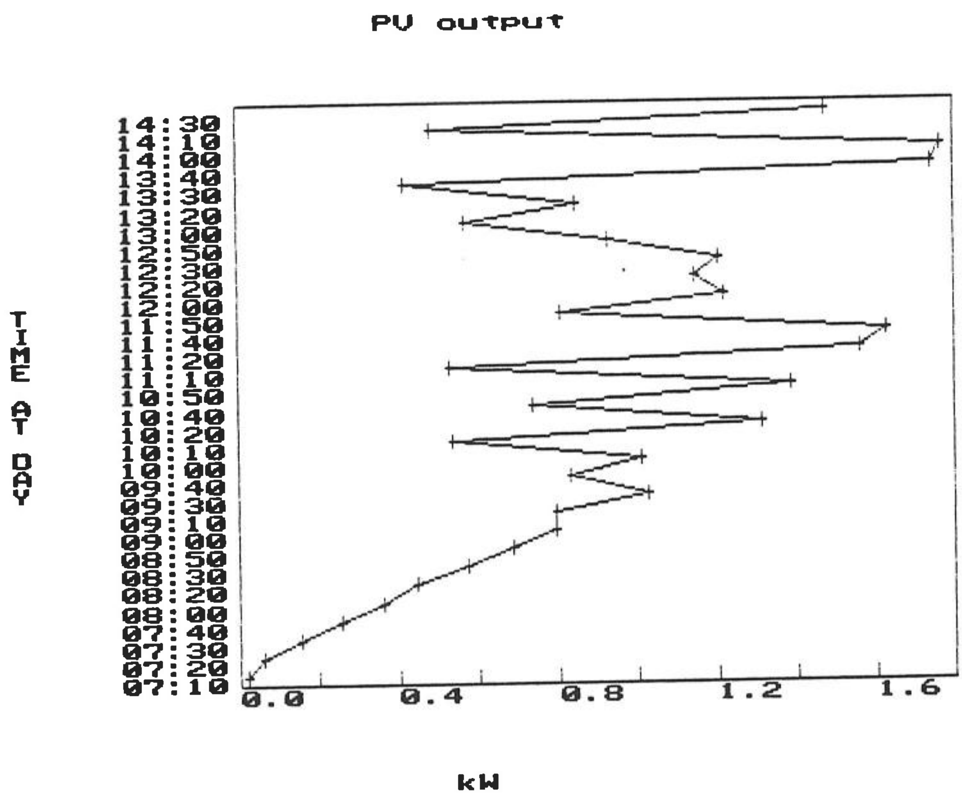
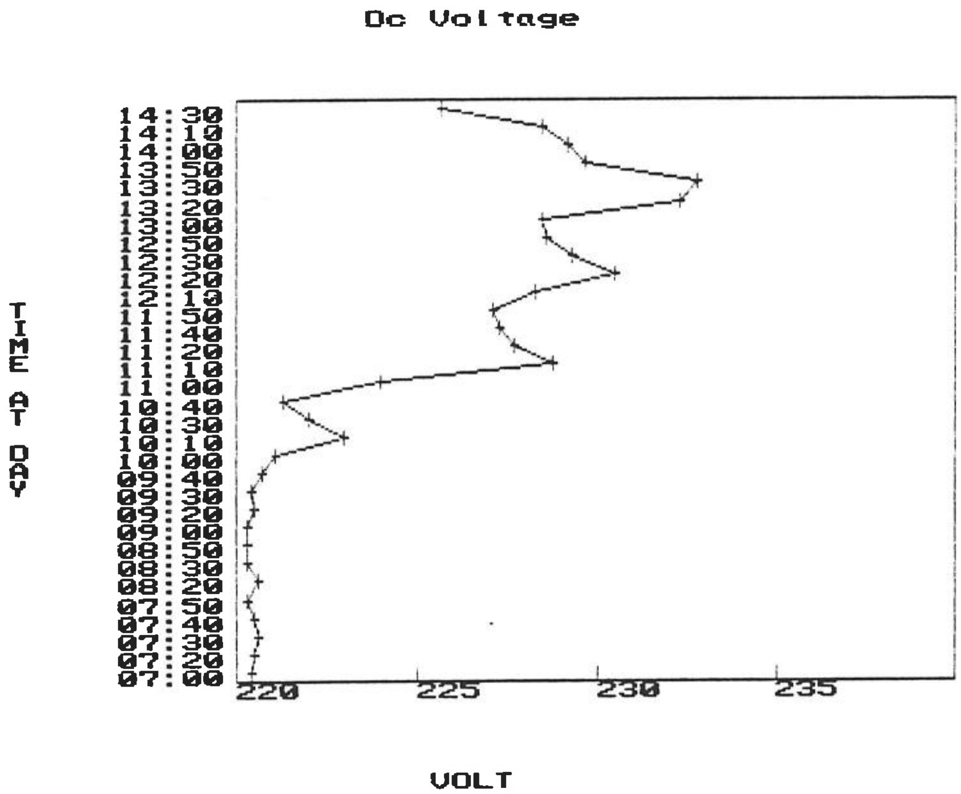


Fig. 6.4.2.d:

Dc voltage:(60) The curves show the bus voltage (the battery voltage) measured on the grid.



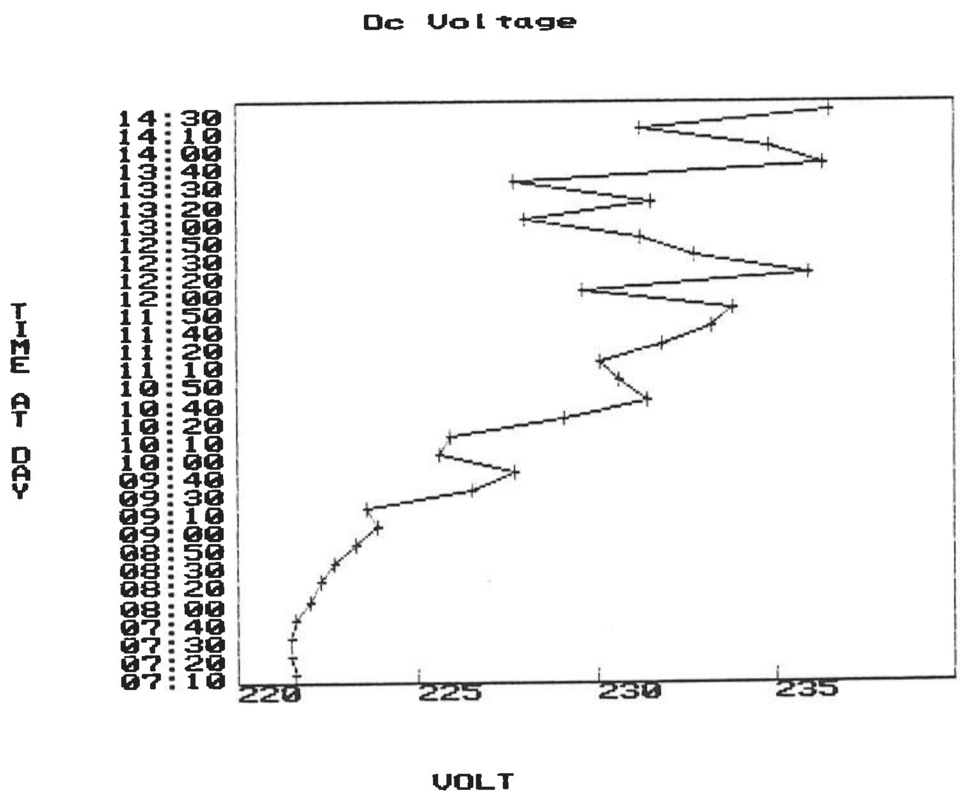
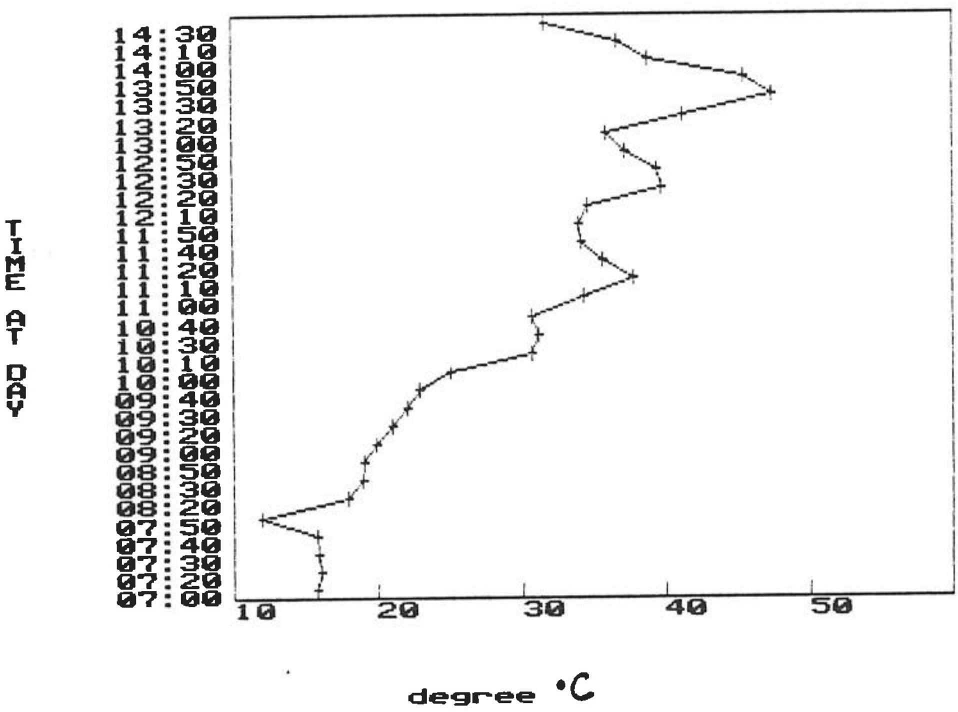


Fig. 6.4.2.e:

PV-temperature:(60) The curves show how the temperature follow the irradiance and production although somewhat delayed and the curves are soft.

PV temperature



PV temperature

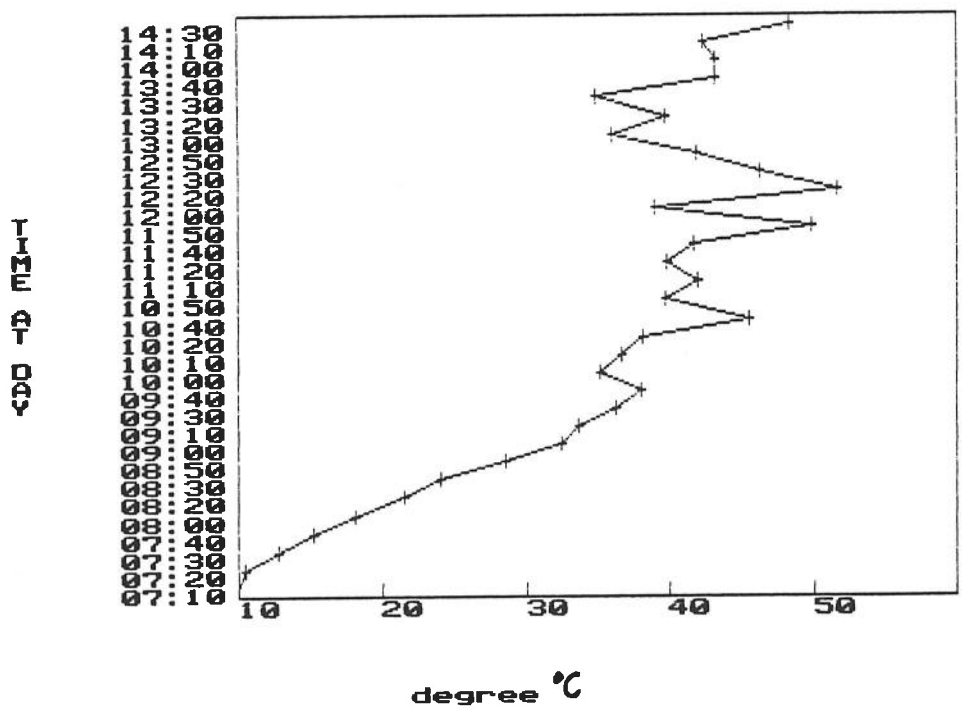
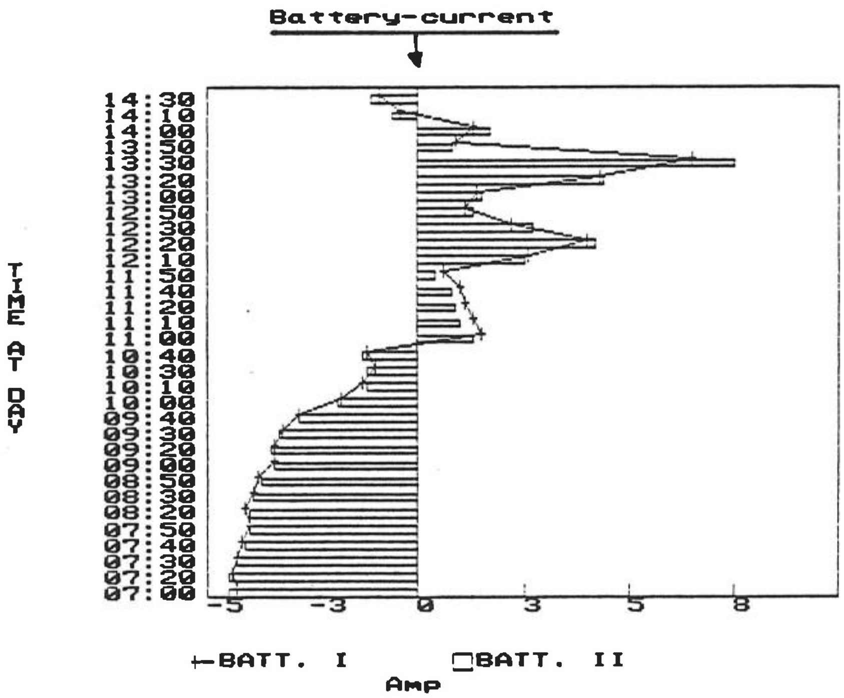
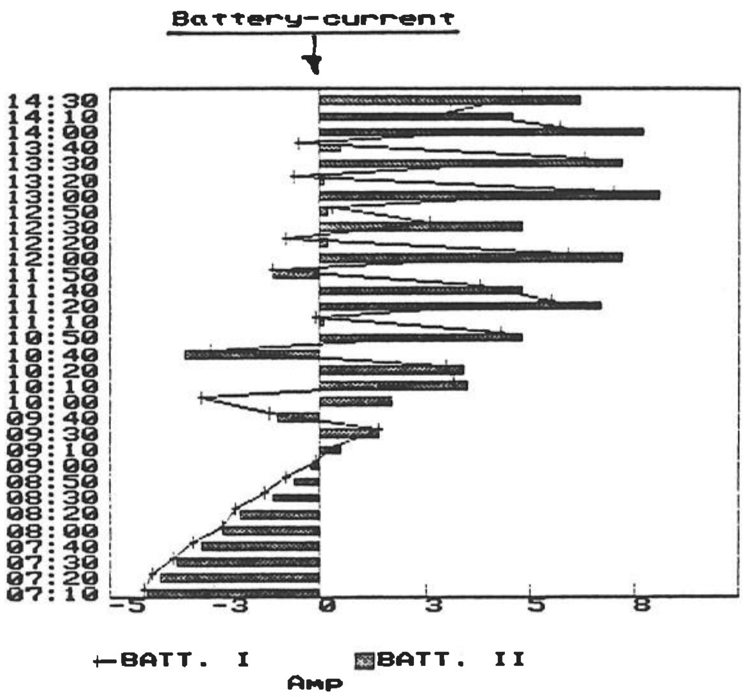


Fig. 6.4.2.f:

Battery current:(10) The curves show instantaneous values for the battery current. It should be noted that there may be one or more scans between the measuring results for the two batteries. This may explain the considerable difference between the battery currents. However, the differences may also be due to the fact that one battery is in a better state than the other.





All curves shown represent instantaneous values measured at time intervals of approx. 14 minutes and give in this way an impression of how large a movement that can be found in such a system. Furthermore, it can be found that two successive days are not at all alike.
If the measurements had been carried out at minor intervals, considerable fluctuations in currents, voltages, etc. could probably be found.

7. Conclusion

This PV-project can be divided into a plant phase (EC contract No.ESC-R-097DK covering the period February 1984 to July 1984) and an operational phase (EC contract No. EN3S-0211-08(SP) covering the period July 1984 to July 1989).

The plant phase which includes design, planning, and installation of the PV-plant is thoroughly described in the final report of October 1984, contract No.ESC-R097DK, so no further conclusion of this part of the project is included in this report.

As regards the operational phase and the experiments attached to this the following can be concluded.

The PV-house has been specially designed for the project and great importance has been attached to integrate the PV-panels architecturally in the roof construction and the result is quite satisfactory.

It is assumed that the tensions in the wooden structure of the roof caused the cover glass of 15 modules to crack during the operational period, however the electric production of the PV-modules has been interrupted on one module only.

On the whole, the PV-modules have functioned to our entire satisfaction during the operational period and module efficiencies of 7% to 12% have been measured dependent on the time of the year, etc. The output voltage of the PV-modules which is applied directly to the battery has been adjusted in the plant via the battery voltage supervision of the DRO, which has handled the on/off connection of PV-modules. The system has functioned without problems during the operational period.

A 10 kVA switch mode inverter has been developed for the project and has functioned quite noisenessly and without problems during the entire operational period.

A microprocessor controlled unit, called the DRO-4, has also been developed for the project and is to supervise and control the PV-plant totally and collect data.
As we consider it quite necessary in an autonomous PV-plant to be able to control the battery totally, the DRO-equipment has been designed so that the battery capacity is calculated continuously just as the voltage of each individual battery block is currently supervised.

During the first 2 years of the project, the DRO-equipment was relatively sensitive to electric noise, causing incorrect measurements and thus some problems with the batteries. An improved version of the DRO was developed and put into operation at the beginning of 1986 and in the last 3 years of the operational period there have been no appreciable technical problems with the DRO equipment.

The operational period has showed that the battery is the most complicated plant component to supervise in practice, but in return the most important one in a PV-plant which operationally is to function satisfactorily as a stand-alone plant.

The PV-plant has been equipped with 2 identical batteries connected in parallel. One of the batteries has been equipped with an automatically functioning air bubble plant. The bubble plant was primarily installed to adjust the acid stratification so that correct densities and thus manual determination of capacity can take place.

According to the battery analysis made at the factory after the expiry of the operational period, the bubble plant has shown that it has an absolutely favourable effect on several important battery parameters.

The comparison to the corresponding parallel battery without bubble plant showed up to 50% less sediment in the battery with a bubble plant just as this battery also had up to 50% more capacity contents than the battery without bubble plant. Therefore, it can be maintained that the bubble plant seems to improve important parameters in batteries in the PV-plant and makes it possible to carry out manual density measurements of a more or less reliable character.

It can be concluded that low-antimony tubular plate batteries seem to be suitable for PV-plants if they are equipped with an automatic battery supervision equipment as e.g. the DRO as well as an air bubble system.
A life of 8 to 10 years for these types of batteries in PV application can be expected.

In the operational period, operational data have currently been collected via the DRO-equipment. Data which have been analysed, examined and processed for the years 1988 and 1989 appear from the graphs shown in the report.

The PV-production from the plant was approx. 25% below the originally calculated production for the years 1988 and 1989. The reason for this is primarily periodic disconnection of the load and deviations as to the weather from "the normal year" which was used at the forecast calculation.

An energy flow analysis has been made in order to determine the system efficiency in periods of a short as well as long duration. The system efficiencies measured seem to conform to made in other PV-plants in the EC.

The project which terminates at the issuing of this final report, has on the whole been carried out in accordance with the objective of the project and must be characterized as successful.

However, there are still some technical ambiguities especially concerning the battery analyses, but the know-how acquired via this project will undoubtedly contribute to solve these problems as well.