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| **Staatliches Institut**  **für Gesundheit und Umwelt**  **(SIGU)** |

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**Exzerpt mit dem Abschnitt**:

**III.5** **Load Management and Solar Power ,**

**der den Einbezug von Fahzeugbatterien in ein Elektrizitätssystem mit hohem Anteil fluktuierender Quellen beschreibt.**

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| **CONSEQUENCES OF**  **DECENTRALISED PV ON**  **LOCAL NETWORK**  **MANAGEMENT** |

**FINAL REPORT**

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**ABSTRACT**

In the CEC funded Joule-II-project "Consequences of Decentralised PV on Local Network Management", a regional network for measuring global solar energy was installed and maintained in the region of Saarbrücken, Germany, from 9305 to 9509. The 15 stations were distributed in a near and in a far distances grid over an area of 31\*45 km2. They were equipped with CM-11 pyranometers and identical PC-based measurement facilities to guarantee similar hard- and software conditions. Over the measuring period, we had a mean monthly availability of 98%.

The basic solar radiation data-pool is available on a 30-sec time-base as condensed files, containing the monthly data for a single station. The conversion to the more convenient Excel-format is combined with the generation of day-files, containing the data of all stations in the measuring net. To facilitate external access to the data-base, the data structure and conversion software is fully described in the Appendix.

In the analysis of solar-data, our central interest is in the "Regional Function (RF)", ie. the regionally averaged solar energy input as a function of time. Because of the daily periodicity, we concentrate on the "*Regional Function of the clearness index (RK)*", expressed by

RK(t) = 1/A \*∫ K(r,t) dr ,  
 region A

Since this function cannot be measured directly, we use as an estimator the mean over the moving averages of the different measuring stations, ie

N l2   
RK(t) = 1/N \* 1/L \* Σ Σ K(rn,tl),  
 n=1 l=l1

where N is the number of measuring stations and L = l2 - l1 + 1 is the number of 30-sec measuring values in the time-intervall that is covered by the moving averages.

On the basis of the above estimator, from all available measuring days we extract eight different radiation patterns for the regional function. Each pattern is ascribed to a distin­guished weather situation. Additionally, extraordinary weather events show distributions especially important for network management. As an aid in doing this classification and also for a coarse overview of the behaviour of the global radiation over the whole region, we have set-up a global-radiation atlas. For every day of the recording period, the most important parameters (mean values, maximum, minimum, standard deviation) characterising the measuring day are collected in tables and diagrams.

For midsummer season, empirical frequency-distributions of the clearness index Kt are communicated and classified for a "snapshot" time between 12.30 - 12.40 UTC and for the most interesting daytime between 9:00 - 15:00 UTC. A classification scheme for dividing the distributions in unimodal and bimodal ones is proposed. In most cases (70% for 12:30-12:40 and 91% for 9:00-15:00), the short time irra­di­ation in the region is characterized by a more or less distin­guished bimodal structure, characterizing the states "sun covered" and "sun free". The parameters describing the bimodal distributions are almost identical for the two time-intervals.

To reveal statistical dependencies between different stations, analysis of spatial correlations of the clearness index was performed for the season around summer solstice. To get rid of trend-behaviour caused by gradual weather changes, we have chosen the method of differences as our primary detrending procedure. For temporal moving averages we used three different time steps, corresponding to intervalls of 10 minutes, 5 minutes and 30 seconds respectively. The daily time-base was restricted to the symmetrical intervall 11:00 - 13:00 local solar time. For station distances above 10 km, the correlational coefficients are vanishingly small. If the distances get smaller, the correlograms approach 1 revealing a dependency on the daily "overall" Kt and on the temporal moving average time.

The final section gives a scenario of the contribution of photovoltaic energy to the energy requirements in future Actual tariff-structures are discussed with respect to their influence on the development of solar energy. Their necessary modifications are examined, when a broader contribution of solar energy to the total electricity production is attained. The cost effective time dependant linear electricity tariff is very suitable for solar energy and can be matched to the complex managing requirements of a solar economy. The inclusion of electric driven cars and the foreseeable new possibilities of information processing and distribution gives new features for the grid-based decentralized pv-production and storage mana­ge­ment within a solar energy society.

C O N T E N T S

INTRODUCTION

**I. STATIONS, EQUIPMENT AND MEASURING CAMPAIGN 6**

**1. Description of Measuring Sites 6**

1.1 Location of sites

1.2 Hardware of SIGUMESS

1.3 Software of SIGUMESS

**2. Measuring Campaign 17**

2.1 Availability of measuring values for the recording period 9305 - 9509

**3. Recalibration and Consequences 25**

3.1 Calibration Check: old and new data

3.2 Comparison of recalibrated data with old data

**II. BASIC ORGANISATION OF MEASURING DATA AND FILES 30**

**1. Standard Preparation of Measuring Files 30**

1.1 From the measuring system to Excel day-files

1.2 Standard analysis of measuring data

**2. Basic Enhancements 35**

**3. Location of Solar Files on Network- and Local Drives 35**

**III. ANALYSIS OF SOLAR-DATA 38**

**1. Regional Solar Energy 38**

1.1 Definition

1.2 Statistical estimation of the regional function

1.3 A similar approach by Kurokawa

**2. Practical Experience 41**

2.1 Global radiation atlas

2.2 Characteristic patterns of global solar radiation

2.3 Extraordinary events

**3. Bimodal Structure of the Regional Solar Energy 83**

3.1 Data pool for the time range 12:30 - 12:40 UTC

3.2 Location of data files

3.3 Results and discussion

3.4 Data pool for the time range 09:00 - 15:00 UTC

3.5 Results and discussion

**4. Spatial Correlations of the Regional Solar Energy 95**

4.1 Description of parameters

4.2 Correlation coefficient

4.3 Correlation of differenced KT

**5. Load Management and Solar Power 114**

5.1 Solar power

5.2 Load, including transportation

5.3 Tariff structure

5.4 Information on the regional availability of energy

5.5 Consequences for the energy managing

**IV. REFERENCES 120**

Appendix I: Overview of Analysis-Procedures 124

Appendix II: Analysis-Procedure for Spatial Correlations 133

Appendix III: Additional Software 141

Appendix IV: Description of the Standard Evaluation for Monthly Files 145

Appendix V: Basic Organisation and Formats of Measuring Data and Files 150



**INTRODUCTION**

This is the final report of a research project funded by the CEC. Our main interest in this project is to monitor and analyse the regional dynamics of the global solar energy. For this purpose, we maintained a network of 15 PV measuring-stations, monitoring the short-time (30-sec) global solar input in the region of Saarbrücken. The measuring system is described in I.

The invariable and permanent, primary data-base is available as monthly files, containing the 30-sec measuring values for each station and each month in a compressed format. Through a set of transformations, described in II and appendix V, we arrive at day-files that are more handy for modern PC-software. The measuring campaign over nearly 28 month furnished a huge quantity of data that can be studied under many aspects. Within the research project, we could evaluate only a small part of the information inherent in the data. Therefore, we have standardised the organisation of the data and described each step, so that external researchers are able to deal with the data without a long work-in time.

From the diversity of global radiation distributions we extract eight categories of typical radiation-patterns, describe the weather situation and give examples for each one (III.2). This section is included with regard to the needs of the practicioner.

In this report, we arrive at a simple *classification of the ensemble of measuring days* by means of basic statistical calculations. Our main statement, derived in III.3, concerns the "bimodal structure" of the regional solar energy. We show, that certain ensembles of summerdays can be put into one of three classes, where the bimodal class contains the highest occupation number. Our results show, that the bimodality is a preserving property of frequency distributions, ie the ensemble of days with bimodal frequency distributions gives itself a bimodal distribution. We give numerical limits about the parameters for each of the three classes.

We extend the results about correlational analysis stated in [10] to the 30-sec-data-base of the Joule-II-project (III.4). The analysis proceeds along similar lines. We show the dependence of the correlation-coefficients from detrending by successive differences of time-series and present diagrams displaying the structure of the correlograms from the selection of different moving-averages steps: 10 minutes, 5 minutes and 30 seconds.

The final section III.5 gives a scenario of the influence of photovoltaic energy to the energy requirements in near future A discussion of tariff-structure is given as well as its con­se­quences on energy management. The inclusion of electric driven cars gives new features for the grid-based distribution and for the storage capacity and economics within a solar energy society.

Nun folgen im Original die Seiten zu den Abschnitten I bis III.4 ,die sich mit der Struktur der regionalfunktion der Solarstrahlung und den Ergebnissen der Messkampagne beschäftigen:

**I. STATIONS, EQUIPMENT AND MEASURING CAMPAIGN** 6

# II. BASIC ORGANISATION OF MEASURING DATA AND FILES Fehler! Textmarke nicht definiert.

**III. ANALYSIS OF SOLAR-DATA** 38

**1. Regional Solar Energy** 38

**2. Practical Experience** 41

**3. Bimodal Structure of the Regional Solar Energy** 83

**4. Spatial Correlations of the Regional Solar Energy** 95

**5. Load Management and Solar Power** 114

Das Problem, wie sich Batterien aus Kraftfahrzeugen und insbesondere aus Elektrofahrzeugen in ein Elektrizitätssystem mit hohem Anteil fluktuierender Stromquellen integrieren lassen, wird behandelt in dem folgenden Kapitel

**5. Load Management and Solar Power** 114

**5.1 Solar power**

**5.2 Load, including transportation**

**5.3 Tariff structure**

**5.4 Information on the regional availability of energy**

**5.5 Consequences for the energy managing**

5. Load management and solar power

In the future, fossil fuels will run short of supply. Therefore, human societies must base their energy consumption in nearly all fields on renewable energies: Solar electricity, -in whatever form is now not so important-, will be used for industrial, public and residental use and also for transportation. May be already in some tens of years, an average household will dispose over photovoltaics on the roof, batteries and/or fuel cells in the basement and an electric car in the garage. Time is to early to give a full description, but let us give some suggestions to this scenario:

**5.1 Solar Power**

In Central Europe, stand alone photovoltaic houses are not an economic solution.The ratio of solar power in summer and in winter and the irregularities of solar radiation are too unfortunate for such a technique. Especially, the periods of low solar income in all parts of the year forbid a stand alone strategy. Therefore we attend the following hierarchy of electric supplies:

* residental PV arrays, distributed over the whole region and interconnected by the regional electricity grid
* local batteries (or fuel cells) in the residental houses and in the cars
* regional central power stations and batteries (or fuel cells or any other kind of short time power storage), in the responsability of the regional utility
* nation-wide, Europe wide and worldwide spread of regions with distributed and grid connected PV arrays on the roofs of houses and other decentralized structures. All these regions together are interconnected on an at least national scale; the nations are Europe wide and Europe is worldwide grid connected with the other partners.
* big fossil (or biomass or nuclear) central electric stations

From the aspect of economy, each unit (house, region, nation, ...) may try to supply an as big as possible part by its own means and to regress to the "parent" structure only in the cases, where the own ressources run short, or where the economy of scale gives advantages. The economy of scale gives advantages for central thermal power stations but not so much for pv-arrays, batteries or fuel cells. Therefore, in these fields private households and local and regional suppliers remain active. In the following we will restrict to the local and regional responsibility.

**5.2 Load, including transportation**

Residental load, car included, must be devided in

* real time load, which cannot be shifted to other time of the day  
   e.g., television, computer, light, electric household machines
* load, shiftable for time periods within a day  
   e.g., washing and other laundry machines, cold storage by freezer or refrigerator
* load, in the average shiftable over several days  
   e.g., car, a new generation of deep freezers

The inclusion of **private cars** into the electric power supply problem gives a new dimension in the magnitude of the task but also in the flexibility of the solution. Any electric car needs batteries, independently from the availability of solar power; therefore the costs of these batteries don’t belong to the solar economy. A rapid exchange of batteries needs a second energy package in the garage or/and on "fuel" stations. The residental provision of solar energy for the car and for the household can be commonly managed, which gives new flexibility. In future, there are no more parking places without electric power for refreshing the batteries. A car will be recharged in the garage as well as on a parking place. The same residental pv will load the car batteries in the garage or, indirectly via the grid, at the parking place. Also, to a limited extent, car batteries will feed energy back to the grid, if prices are high and the on board computer or the grid manager knows, that the energy is available. It is important that the batteries can be loaded even if they are nearly saturated, because in times of surplus solar energy the price will be very low.

Batteries for electrical cars will represent a huge source and a huge load for managing the time dependent solar electricity. For an optimized use of this potential a sophisticated information system is necessary, but exactly this can be attended for the future [19].

**5.3 Tariff structure**

Electricity is a very special merchandise: Today it is technically impossible to store it cheaply in great quantities; therefore production of electricity must smoothly follow the load. Because of the big number of all individual loads within a local, regional, national and international grid the exact coincidence of production and load is not so difficult as it may appear on the first sight. Utilities have given great attention to the construction of tariffs, which should reflect their special economics. On the other hand the tariffs have also reflected the special dependencies of customers to the mighty big utilities.

In the residental domain, where the economic position of the utility is very strong, up to some years ago the utilities in Germany (and also in many other countries) could impose the so called "Grundpreis-tariff" ("basic price tariff"), which consists of a fixed basic price B (in german: "Grundpreis"), which is to be paid without consideration of consumption, and a "kilowatthour-price" or working price p for the unit of consumed energy. A consumer, having received W [kWh] in a standard time period (mostly a month or a year), has to pay

(5.1) P = B + p\*W

with:

P = total price

p = working price, in [DM/kWh]

B = basic price, which was essentially depending from the number of rooms (!)

W = electrical work in [kWh]

The basic price tariff (5.1) was strongly criticized from ecological and economical points of view [12] - [15], because the fixed basic price B reduced the price for the consumption of additional kilowatthours and thus represented a stimulus for wasting energy. Instead of the basic price tariff (5.1), a linear tariff [12]

(5.2) P = p\*W

was proposed, whereby the linear working price p includes the portion of B to the total costs.

After a long debate (see [16] for an ample list of references) the "Bundestarifordnung Elektrizität" (Federal regulations for electricity tariffs) [17] was changed in 1989. The new regulations reduced drastically the basic price B and allowed also to use a linear tariff (5.2). Thereafter more and more utilities changed to the linear tariff. In the german state Saarland, for example, all utilities use the linear or a practically linear tariff.

Taking into account the time dependence of electricity costs the "time dependent linear tariff" was proposed as an extension of the linear tariff [13]:

(5.3) P= pi\* Wi

where

pi = price of kilowatthour in daily time zone i.

Wi = electrical work consumed in the whole time period during the daily time zone i.

W = Wi

The time dependent linear tariff is now allowed by the new tariff regulations [17]. Some utilities, e.g. the utility of Saarbrücken (Stadtwerke Saarbrücken), offer this tariff on an optional basis to their customers. The Stadtwerke Saarbrücken offer the following prices (-taxes are included, valid since 1.1.96-) for the different time zones:

Table III.5-1: Prices of time dependent linear electricity tariff, Stadtwerke Saarbrücken 1996

|  |  |  |  |
| --- | --- | --- | --- |
| **daily time period [h]** | **tariff zone** | **price [DM/kWh]** | **relative price** |
| 6 - 9 | normal | 0,322 | 100 |
| 9 - 13 | high | 0,425 | 132 |
| 13 - 20 | normal | 0,322 | 100 |
| 20 - 6 | economic | 0,218 | 68 |

The ratio between the "economic tariff" ("Spartarif") during night and the high tariff ("Hochtarif") is nearly 2.

It is very interesting, to reason what tariff should be favorable for the evolution of solar electricity. Today, the solar energy used by the producing household itself can be indirectly calculated by the actual tariff, which the houseowner would have had to pay instead of using his own electricity. Then the time dependent linear tariff (5.3) is very favorable, because the maximum of solar input coincides with the high tariff zone. Further, it is recommended, that the price for the surplus electricity feeded into the grid, should be equal to the actual price. Then there is no necessity for measuring and calculating the surplus solar electricity separately and many "unproductive" costs are spared. Under these conditions the time dependent linear tariff is the ideal tariff, because it reflects well the cost structure of the actual electricity load in central Europe and in addition favors solar energy. In other words, the actual cost structure of elctricity, resulting from the load distribution over the day, fits well in the temporal daily availability of solar energy.

These favorable conditions are as long valid, as solar energy is only a small additive electricity source. But under broad solar supply the prices of the tariff zones must be quite inverse as today: cheap on the time around noon and very expensive in the night. Also a seasonal element should to be added.

In the future, when solar energy will be an important part of the energy supply, the time dependent linear tariff (5.3) has to be adapted to the special cost structure. Then the unit prices pi  in equ. (5.3) will depend not only on the time of the day but also on the actual and future regional availabilty of solar energy, on the actual and on the exspected load, on the prices of actual overregional electricity and even on more parameters. Progress in information distribution techniques [19] gives the possibility to involve such complex parameters in the calculation of actual prices and in the automatic optimization of the whole system.

**5.4 Information on the regional availability of energy**

Many actual parameters determine the actual, time dependent costs of an electricty supply based to a greater extent to solar and solar derived production. In a market economy prices should reflect the costs and therewith lead to an optimization of production. For the functionning of this mechanism a full information on the actual situation is necessary. A consumer cannot wait, with the electrical plug in his hand, until the prices are favorable and then switch on. This task must be delivered to an automatic controller or computer, which manages the electrical devices and the storage. The foreseeable technical future is favorable to this option [19], because:

* computer hardware will improve and costs will sink further
* computer software will improve further
* in the near future PC‘s will be available in each household like the telephone today
* inhouse radio connection to the central telephone receiver connected by cable to the telephone grid is just today no more expensive and becomes more and more common
* PC’s in households are linked by telephone grids (including ISDN and other more sophisticated technics)
* cost for information networks will sink

From the above points in can be concluded that in future technical signals can be made available in each house. They can be interpreted by on line computers or by highly sophisticated but cheap electronic controllers. By cable or also by cheap inhouse radio transmission this information can be delivered directly to the controlling unit of the PV generator and the energy managing system. On the same way, information can be transmitted in the opposite direction.

This means:

Full information about the actual state of the regional energy system, combining

- regional solar input

- residental and industrial load

- state of public and private storage capacities

- conditions, including prices, for receiving additional electrical energy from and delivering energy to other regional or national energy suppliers

- short term forecast of regional solar input and middle and longterm weather forecast

- experience of the utility with the time dependence of the load,

is available to the regional utility and can be centrally processed. As a result, price signals for the moment and for the near future can be sent to the small PV power systems and energy managing units.

From this information a home owner could and can make its own decisions. Some people will do so; but I believe that most people will not care on these penny details (for the moment). They can use an intelligent power managing system, may be there will be several different one’s, which makes the decision according to their global instructions. From the total information within the energy system an optimized use of the hard- and software capacities will result.

**5.5 Consequences for the energy managing**

Generally there are some strategies, which are favorable for a cost consciousness energy consumer being at the same time a small scale producer of pv energy:

* at low tariffs: use energy, store energy, avoid to sell energy
* at high tariffs: sell energy, sell or use stored energy, avoid to buy energy

To a certain extent these general rules can be given to an automatic optimizer for the energy management. But there are some questions, which can only be answered by the houseowner and which give further possibilities for optimizing. E.g.: the batteries of a car can be fully decharged, if the car is not needed the next day or at least the next morning. For such questions also a very intelligent energy managing system must rely on "mean" assumptions and risks, that these are not right in a special case and then higher energy prices are to be paid. Nevertheless, in most cases an intelligent energy managing system, perfectly informed by the regional energy information sytem, can make nearly optimal decisions for the actual management and guarantees an optimal state of all storage capacities.

Today, people try to harvest a maximum of yearly energy by their pv installations. In the future the installation of pv arrays has to consider, that not the energy but the price weighted energy has to be maximized. This will lead to the decision, to install PV cells also on west

and east oriented planes, which give a higher output at times, where electricity is expensive. Therefore nearly each roof or facade, which is not totally in the shadow, is appropriate to gain

solar energy. If pv is installed on a site at all, then also the less sunny parts of the house should be used for better profitting from the basic installations!

Winter and summer are properties not of the whole earth but of its northern and southern hemispheres, day and night are properties of a western and an eastern hemisphere. In a solar world, the visionary idea proposed by Buckminster Fuller [18] more than 20 years ago, to connect the whole world by an intercontinental electric power network, must be realized and will equalize seasonal and diurnal inequalities on a great scale. Therefore, the total solar energy supply of the world is a vision, which seems realistic, even if today all technical and economical questions are not yet solved in detail. Taking into account the uncertainties and the danger of alternatives, the total solar future is a necessity.

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