Fraunhofer Institut
Solare Energiesysteme

Compendium of Projects on Rural Electrification and Off-Grid Power Supply

Solar Home Systems – Village Power Supply – Hybrid Systems – PV Powered Appliances – Decentralised Power Generation in Grids – Drinking Water Purification and Desalination – Economic Aspects – Socio-technical Aspects – Development and Quality Control of Components – Test Laboratories – Batteries – Solar Cooling

The Fraunhofer Institute for Solar Energy Systems ISE conducts research on the technology needed to supply energy efficiently and on an environmentally sound basis in industrialized, threshold and developing countries. To this purpose, the institute develops systems, components, materials and processes in the areas of thermal use of solar energy, photovoltaics, solar building, electric power supplies, micro-energy technology, chemical energy conversion, energy storage and rational use of energy.

One focus of our work in the field of photovoltaics is off-grid power supply in areas remote from the grid. World-wide more than two billion people are living without connection to an electricity grid, mostly in developing and threshold countries. However, also in Europe several hundred thousand houses are located in an off-grid situation. Establishment or extension of the grid is very expensive. Renewable energies and particularly photovoltaics offer the most cost-efficient solution for electrifying rural areas remote from the grid. But photovoltaic is only one option. Our main objective is to seek for the most cost efficient solution for any power supply problem. This might include small wind turbines, diesel generators, micro hydro or in the near future fuel cells beside photvoltaics. Optimum solutions could be single household power supply systems or mini-grid solutions with a wide variety of options in between.

Fraunhofer ISE has more than fifteen years of experience in this field. In many countries all over the world, the institute has realized rural electrification projects with photovoltaics.
We are investigating Solar Home Systems, which with their rated power of 50 Wp represent the smallest "ray of hope" for rural areas in developing countries, and with an increasing intensity also larger systems of 1-20 kWp. These larger power supply systems make additional commercial activities or the operation of a clinic feasible. With regard to energy economics, they are interesting as the smallest unit in a decentralized, inter-connected grid. In grid-independent village power supplies, distribution of the electricity is a contentious issue. Our approach of developing the technology together with the local users, always taking social and economic aspects into account, has proven to be beneficial here. This is equally true for mountaineering lodges, where we have provided advice on planning, energy concepts and monitoring, but where we also took responsibility for construction and operation of the systems, in some cases for more than a decade now. The improvement of storage systems for electrical energy as well as quality control and the setting-up of test laboratories have become a vital part of these projects and are within our core competencies.

Recently a special emphasis has been put on water. Clean drinking water is becoming an increasingly high priority. It determines not only the well-being on the consumers, but also the economic strength of a country. Often surface water is drunk without further treatment, with two million cases of illness annually being the direct result. Photovoltaics can provide cheap electricity for pumping and treating water. We also develop disinfection and desalination technology which is appropriate for decentralized water purification. We are concentrating on autonomous powered systems with a drinking water output in the range of 200 l/day to 10 m^3/day.

The corresponding market is worth several thousand million US dollars. We are active in promoting quality assurance and sustainable market development. In this capacity, we advise governments around the world and accompany market introduction programs with our technical, sociological and economic expertise. Supporting local companies in improving the quality of their products and capacity building are in the center of our activities. In the "Club on Rural Electrification" we cooperate with industrial partners to strengthen German photovoltaic exports and co-operation between local and German Companys.

Also an interesting topic especially for countries in the southern hemisphere is solar desiccant cooling, an environmentally friendly technology for air-conditioning, operating without cooling agents. Fraunhofer ISE has set up several air-conditioning systems based on solar energy throughout Europe.

This compendium is a selection of reference projects throughout the past eight years (1993 -

2001) focusing on the above mentioned aspects. It also contains information on the institute's work on decentralized power generation within the grid as well as PV powered appliances. The project descriptions are taken from the respective Fraunhofer ISE annual reports.

Please contact us for any further information and visit our internet pages www.off-grid.de



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Village Power Systems in Indonesia

We conducted sociological and technical investigations in three Indonesian villages with central photovoltaic village power supplies. After staying in each village for several days, the investigation team, with German, French and Indonesian members, introduced technical and organisational improvements.

Michael Müller*, Klaus Preiser, **Petra Schweizer-Ries**, Sebastian Will, Birgit Uenze

We investigated the functionality and acceptance of three central photovoltaic village power supplies in Indonesia. Two of them had been installed by a French consortium in co-operation with the Ministry for Transmigration in Kalimantan and Sulawesi. They are operated according to the pre-payment scheme, which limits the supply of power to individual households and is based on the sales of energy units. The third system, which was equipped with Australian components, had been constructed by the Indonesian Ministry for Technology BPPT in Java. It did not include a pre-payment scheme.

We investigated the technical operation of all systems and interviewed users as well as those persons responsible for the maintenance, operation and electricity distribution in the village (figures 1 and 2). We came to the following conclusions:

- The French village power systems operate well. Only the satellite data transfer, allowing remote monitoring for research purposes, occasionally causes problems.
- The pre-payment scheme has the effect that much less electricity is used than originally planned. The users pay for their energy units in advance.
- The distribution of electricity was regarded as being fair in principle.
- Several inhabitants did not understand how the pre-payment scheme worked and wired bypasses to the meters.
- Operating weaknesses in "charging" the pre-payment systems additionally reduced the acceptance.
- Both the users and the Indonesian project managers would like to be more involved in the French project.
- The system on Java, with unrestricted access of the users to power and energy, is hopelessly overloaded and often has to be repaired.
- Measures to control the electricity consumption, such as subsequently installed power limiters, led to acceptance problems.
- Technical staff to operate the system and a village committee to organise the consumption were present in each village. Rules for usage are being prepared.

Together with the Indonesian partners, we implemented the following measures for one of the French systems:

- correction of minor technical faults
- raising awareness of usage and energy consumption with the aim of controlling the increase in demand and discouraging bypasses to the meters
- involving the local government to assume responsibility for the technology at the end of the project
- preparation of a strategy for permanent use of the system, together with the future Indonesian owners

The conclusion to this project, which was supported by the European Union, is the evaluation of these measures and the preparation of recommendations for the introduction of future PV hybrid systems in rural areas of Indonesia.



Fig. 1: Investigation of a technical system: The photo shows on-site measurement of photovoltaic strings in operation. The measurements are made by an Indonesian staff member.



Fig. 2: Interview with a village inhabitant: With the help of staff from the University of Indonesia, we were able to conduct standardised and open interviews with 50 people from each village. The analysis was based on written records and tape recordings.

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg



Strategies for Grid-Independent Village Electricity Supply - The Example of Rambla del Agua

At present, we are co-ordinating the installation of 17 photovoltaic village power supplies. Engineers and psychologists are working with technical and social concepts on the optimised use of community facilities, and are implementing these together with local enterprises.

Georg Bopp, Claudia Casper*,
Johannes Koops,
Petra Schweizer-Ries, Gisela Vogt

Since January 2000, we have been co-operating with partner institutions from Spain, France, Portugal and Switzerland on the construction and further development of community-based, off-grid village power supplies in Spain.

In addition to the co-ordination, we are responsible for the following tasks:

- technical further development of information transfer and energy distribution; an infobus transmits data on the energy consumption of the individual households
- organisational and social support of the systems and their users to facilitate permanent operation

We are implementing research results from the engineering and social sciences directly in the demonstration project. While we are concerned primarily with the scientific aspects, the Spanish company, TTA, and the University of Vigo are constructing the demonstration systems in Spain and Latin America.

The work up to now has concentrated on socio-technological measures in the village of Rambla del Agua in Andalusia. There, 38 households have been supplied since 1997 with 230 V AC electricity from a system comprising a 10 kWp PV generator, a 3660 Ah/48 V battery and a 10 kVA back-up diesel generator.

We conducted 15 interviews with users of photovoltaic electricity, 3 with non-users and a further 6 interviews with key persons involved in the operation of the PV system at various levels.



Fig. 1: Solar festival in Rambla del Agua, Andalusia.

The interviews indicated:

- The users are basically very satisfied with the power supply, but would welcome further technical improvements.
- There is great interest in more information on the system and its use.
- The household displays on "electricity distribution" and demand adaptation are not often used.
- Identification with the system is very strong in the village; the residents accept complete responsibility for service and maintenance.

We improved the automatic transfer of information on the status of the photovoltaic system. The status information determines the current electricity tariff via an energy monitoring instrument, and thus influences the user behaviour. Errors in the data transfer caused faults in the energy monitoring instruments; they were no longer able to fulfil their purpose. We introduced signal amplifiers, which rectified the errors.

In addition, we supported the organisation of a solar festival (fig. 1). The "Fiesta del Sol" was important to the whole process: It drew the attention of neighbours and politicians to the new technology, reinforced the identification of the villagers with their PV system and raised awareness about its sustainable use.

Further research work within this project, which is supported by the EU, will concentrate on another village. New technical and organisational measures are intended to guarantee permanent operation and an optimised distribution of energy there.

* free-lance

Photovoltaically Powered Battery Charging Station and Domestic Water Supply - Evaluation and Monitoring of a Project in Thailand

Photovoltaically powered water pumps and battery charging stations are presently central aspects in supplying basic needs in rural Thailand. Two of these systems are being monitored in cooperation between Fraunhofer ISE and the Solar Energy Research and Training Centre SERT at Naresuan University in Phitsanulok, Thailand.

Edo Wiemken, Orlando Parodi



Fig. 1: A battery is transported home from the charging station in Huay Dua village after being recharged. The battery, television, etc. must be paid for by the users; use of the charging station is free.

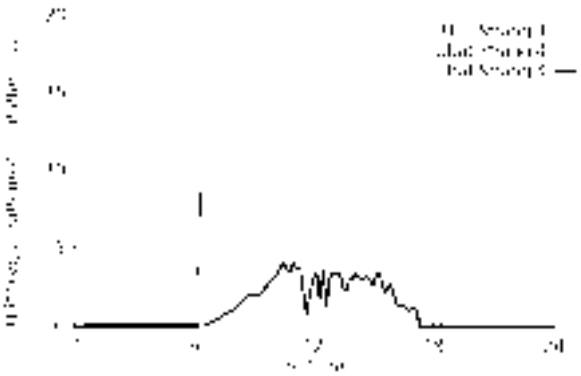


Fig. 2: A day at the battery charging station: Daily profile of the open circuit voltage of an unused PV string (Voc string 1), the charging voltage (Vbat string 4) and the charging current (Ibat string 4) for a battery connected to string 4. The battery was collected shortly before sunset.

Despite major electrification projects by the state utility, large areas of rural Thailand are not connected to the public grid. Thus, grid-independent electrification has played an important role for a number of years. For village electrification, the decision was made for largely standardised battery charging stations, which are powered by PV generators. Five parallel charging units are housed in a charging station hut in the village. The inhabitants bring their batteries for charging in the morning and collect them again late in the afternoon. In the household, the battery meets the power demand for light, radio, television and other small appliances. About 1000 such systems are already in operation.

Another problem is the rural water supply. During the dry season, which lasts several months, even large household rainwater tanks quickly run dry. More than 600 photovoltaically powered water pumping stations provide a solution by pumping domestic water from artificial dams to the village centre.

One PV battery charging station and one PV pumping station are being evaluated with financial support from the Deutsche Forschungsgemeinschaft (DFG) and the Gesellschaft für Technische Zusammenarbeit (GTZ) from Germany and the National Research Council of Thailand NRCT. The required monitoring systems were implemented and taken into operation during the second half of 1997. The consumption patterns of the people who use the battery charging station will be analysed.

Evaluation of the data, together with extensive system simulation of both stations, is intended to allow comprehensive interpretation and assessment of the system operation. As these are the first measurements of PV systems of this type in Thailand, quantification of the revealed optimisation potential is particularly interesting with regard to the large number of installed systems.

Power Supply for Consumers far from the Public Grid in Remote Rural Areas

Project staff: H.Gabler, G.Hille, J.Kuhmann, O.Parodi, N.Pfanner, K.Preiser, W.Roth, P.Schweizer

A working group made up of technicians, social scientists and economists was newly formed. Together with partners located in the region, the different aspects of supplying energy to consumers far from the utility grid in remote rural areas are being worked on.

New working group at ISE

In the forseeable future, a large part of the population world-wide will have no access to a public utility grid. Decentralized solar energy use can improve the living conditions through the availability of energy services such as lighting, radio and television, drinking water, health services and communications. Based on the experience that the Institute has gained with the energy supply of remote buildings in Europe, activities outside Europe were intensified e.g., in cooperation with Argentinian and Nepalese partners.

A newly created, interdisciplinary working group at ISE comprised of people with technical, social and economic competence are working in close contact with local people on the different aspects of the technology development of renewable energy systems. Up to now, the work has concentrated on three main aspects:

- Improvement of the quality of systems and their components for installation in remote rural areas.
- Planning and implementation of joint pilot projects in order to gain systematic experience for the further development of projects.
- Educational instruction from experts in order to enable autonomous distribution of photovoltaics on location.

Quality of components and systems — the ISE DC Laboratory

A European-wide market overview on appliances requiring DC voltage was prepared at ISE and was published in a practical handbook together with test results of selected devices.

As commissioned by the gtz, German Society for Technical Cooperation, in winter 1993/94, 28 charge controllers available on the German market in the power class between 50 and 200 W, as well as five locally produced controllers from Senegal, Tunesia and the Philippines were tested for their suitability for small photovoltaic systems – so-called *Solar Home Systems* (SHS). An outstanding result was that the cost of these devices was hardly a reflection of their quality. Among the most expensive devices, there were some of extremely poor quality, and several of the inexpensive devices belonged to the best quality achievable on the market today.

Tests carried out on electric devices and system components up to now indicate a large potential for optimisation in this area. At ISE a laboratory having the most modern equipment was set up. Here tests and new developments for public and private project partners can be carried out.

Solar Home Systems for a Village in Argentina far from the Public Grid

Together with the Universidad Nacional de San Juan (UNSJ), every house in a remote village in the province of San Juan, Argentina was installed with a *Solar Home System*, with which the electricity demand for lighting, radio and television can be met. In the school a large PV system provides electricity for the lighting, radio station, video recorder and the communal refrigerator. In addition to the technical solution of the electricity supply, inclusion of the consumer in the entire planning and installation process is a major objective. By this strategy, a responsible interaction with the new technology, its advantages and restrictions can be achieved.

Together with the consumers, the previous energy consumption was analysed, the energy consumption in the future was determined and local participation in installing the system was established.In a detailed contract concerning maintenance and use with a 5 year lifetime, the legal and financial responsibilities of the consumers on one hand and of the UNSJ on the other hand are regulated. Each family participates with a one-off installation fee for the system of $U.S.40 as well as a monthly

Abb.45: Construction of a ‚Solar Home System' in a remote village in Argentina



rate of $U.S.10. After 5 years, the ownership and maintenance responsibilities of the system will be handed over to a suitable organisation.

As far as possible, components made in Argentina were installed. A team made up of technicians and social scientists from the UNSJ, the state's agricultural organisation INTA, ISE, a private electrical company and a government representative for the province planned and installed the systems and taught the residents in the village how to handle the new technology. In future co-operative work with UNSJ, the system's functional capability and its acceptance among the residents will be investigated.

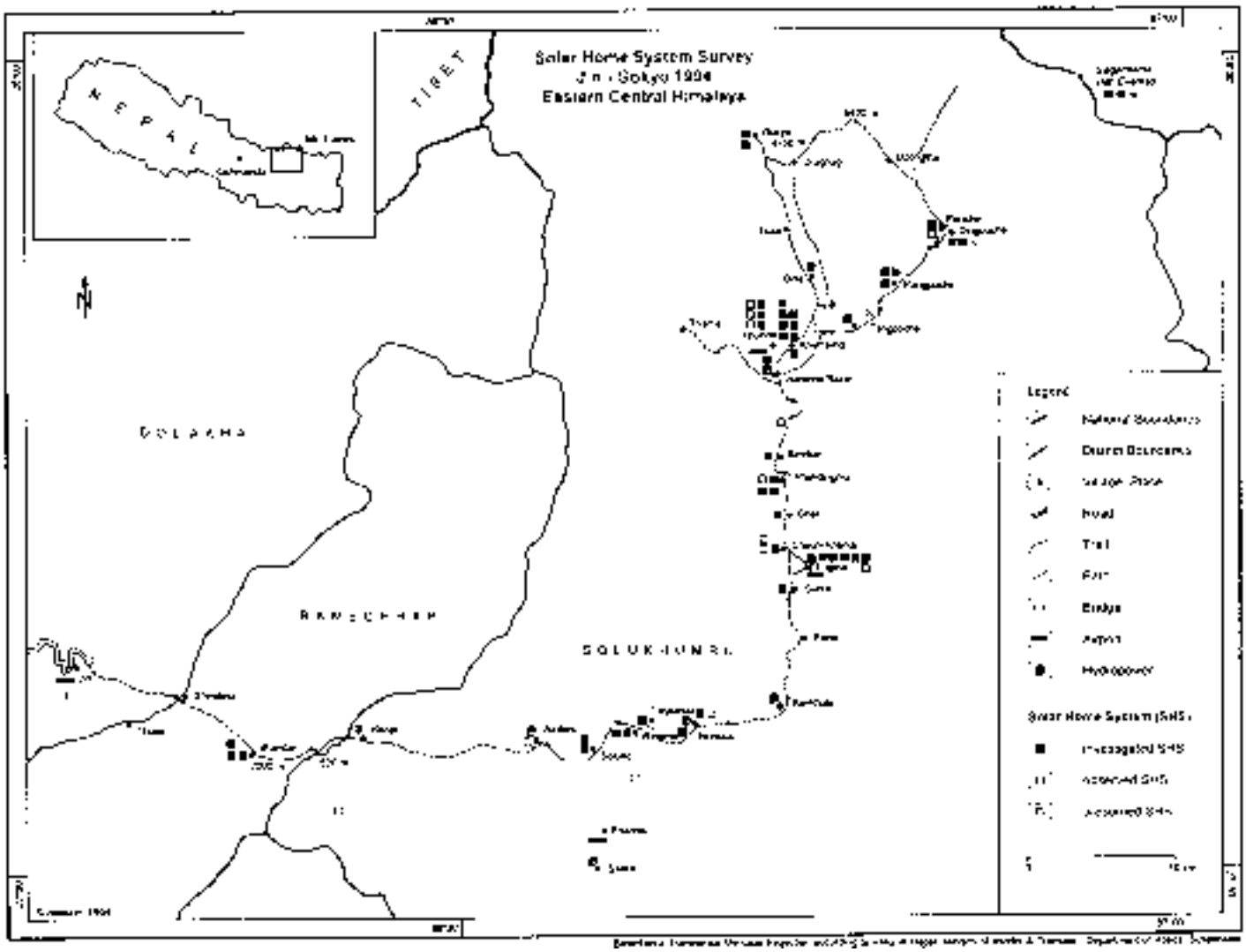
Resource Study and Market Development of the Solar Home Systems in Nepal

In a resource study on location, the type and amount of the energy demand in the high mountain region in Nepal was investigated and contact was established with the indigenous organisations that concern themselves with solar energy.

An inquiry on PV systems along the main route to Sagarmatha National Park in central Himalaya was carried out. A surprising number of over 50 Solar Home Systems was ascertained, and the operators were questioned about their experience with the systems. They had installed and maintained the systems on their own initiative and, in part, incurred a large financial burden without public financial support. Out of ignorance, most avoided including a charge controller, which helps to protect the batteries, and had neglected proper maintenance procedures.

The Dept. of Electrical Engineering at Tribhuvan University recently established a course of studies in photovoltaics. It concentrates on small PV systems in Nepal, which in cooperation with ISE, will be investigated in more detail.

Fig. 46: Geographic distribution of 50 'Solar Home Systems' in the central Himalayas. An example for the emergence of a spontaneous market for PV systems.



Powerful Electronics for Hybrid Power Supply Systems for Telecommunications Facilities

We design and construct the controls for autonomous power supply systems based on a photovoltaic generator, a fuel cell with an optional electrolyser and a 12-month hydrogen storage unit.

Jochen Benz, Bruno Burger, Jürgen Ketterer, Michael Neutz, **Dirk Uwe Sauer**, Heribert Schmidt

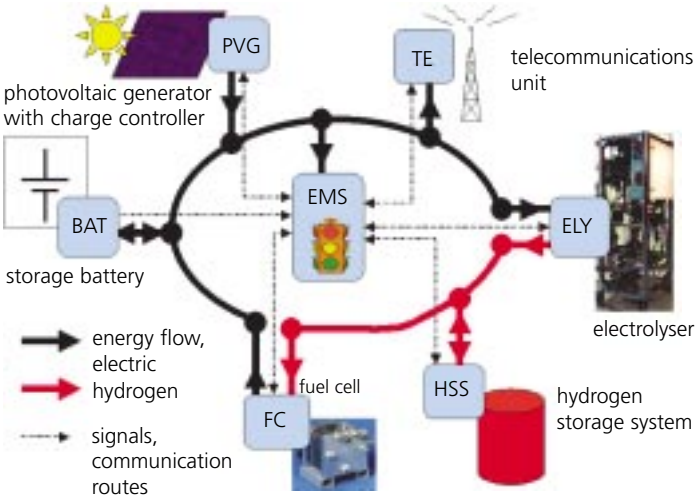


Fig. 1: Block circuit diagram of the discussed hybrid system for telecommunications facilities.

Hybrid systems with photovoltaics and an auxiliary generator are a good option for supplying power to transmitters, as they are often located at remote sites with difficult access. Expensive installation of electricity cables can be avoided or complicated fuel transport can be reduced. The auxiliary generator guarantees supply reliability even during periods with little or no sunshine, while the major share of the demand is met by the photovoltaics. Complete independence from external sources can be achieved with an additional seasonal energy storage unit (fig. 1). Supply reliability is decisive for telecommunications systems. Modern electronics and software are essential to ensure that the economic and lifetime boundary conditions are met. The central control unit for the system is a microcontroller-based energy management system (EMS), which monitors and controls all energy flows (fig. 2). In an EU-funded project, we are testing modular concepts for commercial applications. The most recent results from systems simulation and storage system research are taken into account.



Fig. 2: Electronics of the energy management system to control hybrid systems.

Determining the battery state of charge

One central quantity for operation management is the state of charge of the battery. We determine it with an algorithm which automatically adjusts the parameters for the underlying battery model during operation. Appropriately adapted precision sensors ensure that the results are sufficiently accurate.

Seasonal hydrogen storage unit

The electrolyser needs half an hour to initialise before it can convert excess power from the photovoltaic generator into hydrogen. The energy management system recognises stable insolation periods, when it is worth operating the electrolyser. The EMS monitors the filling of the metal hydride storage unit and determines the amount of gas stored. In darker periods during the winter months, it starts the fuel cell to maintain the power supply at the level needed.

Safety and defect detection

The EMS continually checks the system components and gives notification of any defects by radio to a central station, before the power supply falls too low.
The electric controls for the gas valves of the fuel cell were designed so that faults in the electronics itself can be recognised and unwanted gas escape can be prevented in all cases.

Modular concept

In constructing the hardware, which is also reflected in the operation management software, we designed the units to be as independent as possible. They are coupled via an energy bus and connected to the central unit with a communications interface. A safety loop is foreseen as an option. This means that a developed system can be modified simply and adapted to other boundary conditions. A PV-fuel cell system based on this concept was installed in Madrid in June, 2001. Experience from this field test is influencing the development of the system with seasonal storage, which will be commissioned early in 2002.



Stand-Alone Power Supplies for Telecommunications, based on Photovoltaics, Fuel Cells and a Hydrogen Seasonal Storage Unit

We develop stand-alone power supplies for telecommunications systems. They are based on photovoltaic generators with hydrogen-fuelled fuel cells as the back-up power supply. In a second step, an electrolyser makes complete autonomy feasible.

Jochen Benz, Beatrice Hacker, Angelika Heinzel, Hans-Georg Puls, Dirk Uwe Sauer

Repeaters for telecommunications are often located in remote areas. A combination of a photovoltaic generator, a fuel cell and a conventional battery can make them independent of logistically complicated fuel deliveries. For the first development stage, the hydrogen is still delivered in gas cylinders. In the second stage, we will integrate an electrolyser together with a hydrogen storage unit into the system. This will result in a completely autonomous system with seasonal energy storage. Minimised maintenance and 100% availability of electricity is given the highest priority.

At present, we are developing prototypes under the leadership of Alcatel, Spain, drawing on the experience gained with the self-sufficient solar house in Freiburg (commissioned in 1992). We are now further developing the system concept, which was demonstrated for the first time then, for broad technical application. In addition to developing concepts, we are involved in the project with planning tools and system components.

System design

In order to achieve continuous system availability at low cost, we are optimising the system design on the basis of lifetime costs. To this purpose, we are using and extending our TALCO simulation program (technical and least cost optimisation). The program optimises the complete system after all the technical and economic parameters describing the components have been entered. The output is the system cost and the dimensions of the individual components.

Seasonal Energy Storage System

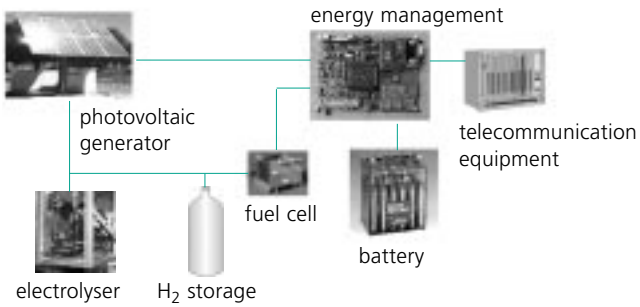


Fig. 1: Schematic representation of the stand-alone power system with seasonal hydrogen storage. This system will be implemented in the second project step, in co-operation with manufacturers of photovoltaics, fuel cells and telecommunications.

For the system to be implemented in the first stage, with a fuel cell and externally supplied hydrogen, the price of the hydrogen cylinders turned out to be the most critical parameter for the system dimensioning. The costs for generating a kWh electricity from hydrogen are two to three times higher than for photovoltaic generation. Thus the system design varies considerably, depending on the price development assumed for hydrogen.

Energy management system

The central control unit of the system is an energy management system (EMS), based on a microprocessor unit with an extremely low electricity consumption. The EMS controls and monitors all the energy flows and the system state. It calculates the battery state-of-charge, connects in the electrolyser and fuel cell at the optimal times and make automatic tests of all components, including the battery. Remote monitoring is possible via the EMS.

Elektrolyser

As illustrated in fig. 1, the stand-alone power supply will also become independent of hydrogen deliveries in the second stage. Hydrogen will be produced in summer with the excess electricity from the photovoltaic generator, and stored in a metal hydride unit. The hydrogen is produced in a pressure electrolyser with a polymer electrolyte membrane, which was developed at Fraunhofer ISE. The result is a system with seasonal energy storage (electrolyser - hydrogen storage unit - fuel cell). The power will be about 1 kW. Outdoor operation of the electrolyser at temperatures below the freezing point presents a particular challenge, if maintenance is to be kept minimal. At present we are working on measures to allow the electrolyser to "survive" the winter.

The PV fuel cell system will be taken into operation under real outdoor conditions in Madrid in the first quarter of 2001, and the system with seasonal storage will follow in the second quarter of 2002. The EU is funding the project.

Grid-Independent Power Supply for Repeaters in Mobile Radio Networks

Repeaters are digital radio signal amplifiers, which increase the connection reliability of mobile telephones within radio cells and raise the accessibility level in mobile radio networks. They receive the conversations, which have been converted to digital data, by radio, process them and transmit them on to a base station, also by radio. In rural areas and in mountainous regions, repeaters often have to be installed and operated at sites remote from the public electricity grid.

R. Kügele, J. Kuhmann, **W. Roth**, W. Schulz, A. Steinhüser

At Fraunhofer ISE, a photovoltaic/thermoelectric hybrid system has been developed as a power supply for repeaters (e.g. mobile telephone repeaters) and integrated into a newly constructed repeater station (fig. 1). A modified thermoelectric generator from the Canadian Global Thermoelectric company has been used as the auxiliary generator (fig. 2). A microprocessor-controlled energy management system (EMS) allows fully automatic operation with minimal use of fossil fuels and appropriate operation management.

As the auxiliary power supply can support the PV generator in supplying power to the load during periods with little sunlight, a very reliable power supply is achieved. Further, the dimensions of the PV generator and the battery capacity can be reduced without affecting the supply reliability. In Central Europe, for instance, the size of the PV generator can be reduced to a third of that needed for an exclusively PV system, if only 10 % of the annual demand is met by the auxiliary generator. This allows a compact construction of the photovoltaic hybrid system and helps the numerous requirements on isolated telecommunications facilities to be fulfilled. The implemented energy supply system is less susceptible to theft and is practically vandal-proof. Flexible installation options inside the repeater station and separation of the gas technology and the electrical installation are further advantages. The overall structure is designed for operation under extreme environmental conditions.

Fraunhofer ISE is currently testing the photovoltaic hybrid system under realistic operating conditions. Sophisticated measurement technology allows all system components to be measured comprehensively and continuously, and provides the basis for informative analysis of all the data needed to evaluate the entire system.

With appropriate modification, the photovoltaic hybrid system is also suitable as a reliable power supply for e.g. environmental measurement stations, aviation safety equipment, signal systems and traffic-guiding systems.



Fig. 1: Repeater station with an integrated photovoltaic generator.



Fig. 2: Thermoelectric auxiliary generator inside the repeater station.

The Self-Sufficient Solar House, Freiburg

Project staff:
A.Goetzberger, K.Voss, G.Bopp,
K.v.Dohlen, H.Jägle, A.Häberle,
A.Heinzel, H.Lehmberg

The intention of the research on the 'Self-Sufficient Solar House' is to show that with a low energy house it is possible to meet the entire annual energy demand of a residential building solely through a decentralised solar energy supply. During the mid-winter months, the unfavourable ratio between the energy demand and the available solar irradiation is compensated for by the stored hydrogen, which has been produced by the PV powered electrolysis during the summer months. The building was completed in October 1992 and has been inhabited since that date.

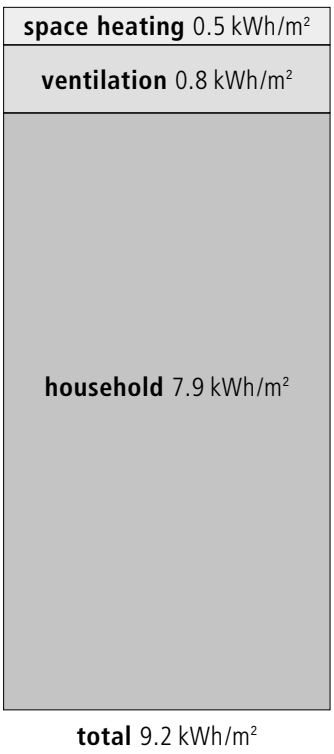


Fig.5: Measured energy parameters, 1994. Data given in kWh final energy per square metre living space.

Energy consumption (gas, electricity) used for heating the household water does not occur, since it is heated exclusively by the solar collector or by the waste heat of the fuel cell.

Energy Consumption and Operating Figures

Based on the results from the first year of operation, optimisation measures as well as a large number of detailed investigations were carried out. The results of the energy consumption measurements confirm the self-sufficient house's outstanding position within the field of energy optimised residential buildings. Through efficient energy use, the household energy consumption (electricity, gas used for cooking) was decreased by 60% as compared to the annual energy consumption of an average German household. This was achieved without a loss in comfort. Maintaining a comfortable indoor temperature throughout the year was achieved solely by passive solar energy measures (windows, TIM) in conjunction with quantitatively as well as qualitatively improved thermal insulation and an efficient ventilation heat recovery system. Supplemental heating generated by the catalytic combustion of the stored hydrogen was limited to a few days in the year.

Seasonal Energy Storage with Hydrogen

During the summer, 266 m^3_{STP} of hydrogen gas (corresponding to 931 kWh_{HO}) was produced and conveyed to the pressure storage tank. Thus, the membrane pressure electrolyser (2 kW rated power), developed at ISE, proved its reliability as a working part of the entire process periphery. Out of this, important experience was acquired about the long-term operation of such components which are not yet commonly implemented for daily use but will be used in future projects. An important milestone in this work was the successful installation and operation, in cooperation with Siemens AG, of the entirely new fuel cell system. In the fuel cell the stored gases of hydrogen and oxygen are reconverted by an electrochemical process to electricity and heat with water as a reaction product (reverse reaction to electrolysis). In co-generation, the waste heat from the process is used as supplementary heating for the warm water supply.

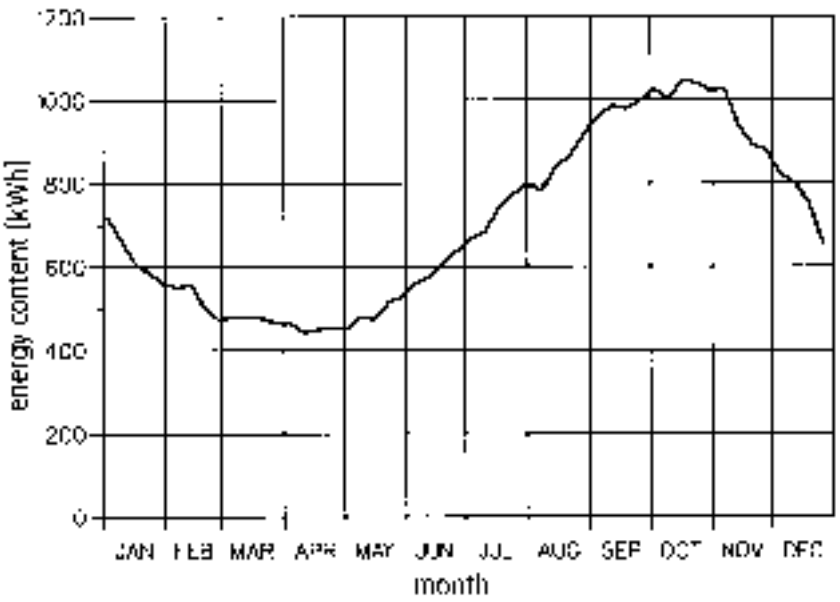


Fig 6: Change of the energy content (upper heating value) in the hydrogen tank used as seasonal storage. The rise of the energy content between April and October 1994 is due to the operation of the electrolyser during simultaneous gas consumption for cooking. From November on, the fuel cell generated current again from the gases. In this way, 178 kWh electricity were produced up to the end of the year.



Energy Planning Guidelines for Mountain Lodges

Renewable energy is an ideal alternative to diesel generators for supplying electricity to mountain lodges. We have summarised the most important points for successful conversion in a set of planning guidelines.

Georg Bopp, Klaus Kiefer,
Dirk Uwe Sauer

The planning guidelines help to determine the energy demand and set up an environmentally acceptable power supply for mountain lodges and shelter huts. They are addressed both to owners and operators (e.g. wardens and leaseholders) and also to engineering offices and system planners. They are intended to support all involved in the planning process, and thus contribute to the development of high-quality power supply concepts.

The guidelines are based on our experience with more than 45 photovoltaically powered, off-grid houses and mountain lodges. This has shown that the first step is to determine the existing energy consumption and ways of reducing it.

The standard method to calculate the potential for saving electricity uses consumption measurements and calculations for the individual project concerned. As a supplement, for the first time we have proposed three methods based on energy coefficients. The coefficients were derived from 15 systems which have already been measured. We analysed the data for correlations between the electricity consumption and the amount of installed equipment, number of guests, table capacity, number of beds, the menu, length of the ascent to the lodge and the water consumption. With the assumption that most of the appliances used are from the energy efficiency class A, finally three reliable correlations were identified. As an example, fig. 1 shows the correlation between energy demand and the number of guests for large lodges, which have more than 4 000 overnight guests per season or are open the whole year.

For this category of lodge, the energy demand can be calculated quickly and sufficiently accurately using the coefficient for "energy consumption per guest", without the need for measuring consumption.

Once the energy-saving potential has been determined, the guidelines show how the remaining energy demand can be met in an environmentally acceptable way using regenerative energy sources, taking the particular boundary conditions in the mountains into account.

A corresponding decision diagram includes e.g. photovoltaic systems, heat/electricity co-generation plants fuelled with rapeseed oil, solar collector systems for domestic hot water and tiled stoves fuelled with wood pellets. Using this diagram, the reader can develop a consistent overall concept.

To validate the assumptions, we prepared an energy concept for the Göppinger Lodge of the German Mountaineering Club DAV, thereby proving the practicability of the guidelines.

The guidelines were financed by the German Environmental Foundation DBU. It has initiated a funding programme for exemplary, environmentally acceptable supply and disposal services for off-grid mountain lodges. This includes measures for power and water supply, and disposal of garbage and waste water. To make a grant application with the DBU, a detailed analysis of the existing situation and presentation of the concept are required. The guidelines simplify this step considerably.

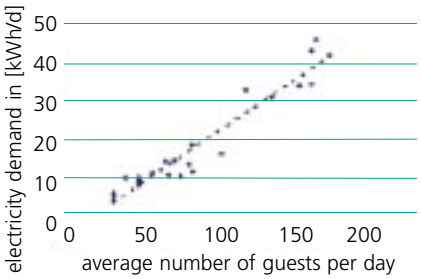


Fig. 1: Average daily energy demand as a function of the average daily number of guests.

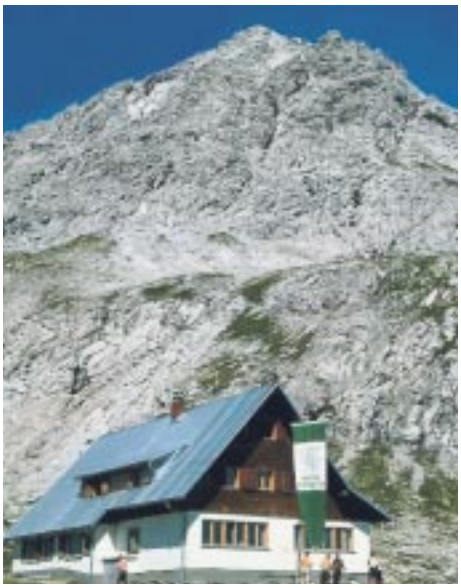


Fig. 2: The energy planning guidelines were validated for the first time for the Göppinger Lodge.

Experience from 100 Accumulated Years of Operating PV Hybrid Systems

Grid-independent photovoltaic systems with a battery storage unit and an auxiliary diesel generator provide remote buildings with electricity. Fraunhofer ISE has been working for more than 10 years on the development and implementation of grid-independent photovoltaic systems. We investigate reliability, the type and extent of malfunctions and the maintenance requirement during operation.

Georg Bopp, Rainer Neufeld, Stefan Senft, Martin Schulz

Like every other technical system, stand-alone PV systems require regular maintenance.

Within a project supported by the German Federal Ministry of Education, Science, Research and Technology BMBF, we are investigating the operating performance of around 30 systems. About half of these provide power to lodges of the German Mountaineering Club (DAV) in exposed positions at altitudes of up to 3000 m. The remaining systems generate electricity for private buildings, hikers' inns or isolated farms. The energy demand ranges between 0.1 and 60 kWh/d. The oldest objects have been operating for more than 10 years.

In order to obtain reliable information on the maintenance work needed, we inspect the systems regularly. We have prepared individual inspection manuals to this purpose and made several sample inspections. All of the remaining inspection work is done with the help of the inspection manuals by local companies as far as possible. The relationship between the operator and the maintenance company is defined by a maintenance contract which we formulated.

On the basis of the entries in the inspection manuals and the system logbooks, we analyse the cause of malfunction, prepare statistics on the effect on operation, and determine the average probability of malfunction and the need for optimising individual components or the overall system.

To date, 22 systems with a total of 116 operating years are included in the investigation. Among these, 261 mostly independent malfunctions have been registered and classified, resulting in an average frequency of 2.3 malfunctions per system and year. Figure 1 illustrates the average frequency of malfunction per system and year for the individual components, an extract from the overall statistics.

About 20 % of the malfunctions can be remedied by the user - usually after consultation by phone. In all other cases, an expert is required, who can solve the problem only by replacing a component for three of four incidents.

About half the malfunctions limit the electricity supply noticeably, the rest hardly affect the user. It is pleasing to note that practically no event led to complete breakdown of the system. This is due to the back-up provided in almost all systems by the presence of the PV system and the diesel generator. In general, system malfunctions are due to component failures. These have a wide variety of causes, with lightning strikes or operating errors occurring only occasionally. Most of the failures are due to aging of the components. This share can be reduced by optimisation of the equipment.

The replacement interval of less than 10 years for the solar generator, as indicated in fig. 1, is not representative, as about half of the systems were equipped with a model which displayed production-related malfunctions after about five years of operation.

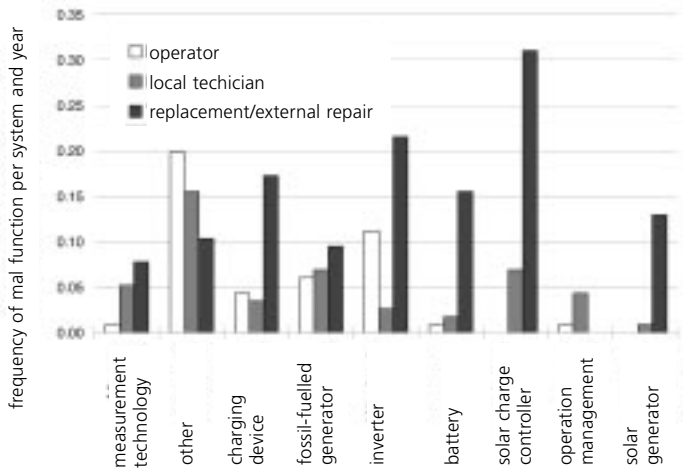


Fig. 1: Frequency of malfunctions per system and year, classified according to the components and the effort needed to remedy the disorder



Monitoring by Fraunhofer ISE Maintains High Quality Standards for Solar Systems on Mountain Lodges

Fraunhofer ISE has already been co-operating with the German Mountaineering Club (DAV) for ten years in the application of solar energy to mountain lodges. Initially, there were only a few technically mature charge controllers and inverters on the market, so that the emphasis was on technological development and practical tests. Today, system optimisation, standardisation and quality assurance are the primary aspects. The Institute now supports about 30 lodges with its monitoring programme.

Klaus Kiefer, Georg Bopp, Martin Schulz*, Petra Schweizer-Ries, Eberhard Rössler*

In the "EURALP" joint project, which is funded by the Commission of the European Union, 17 off-grid photovoltaic systems on mountain lodges belonging to the DAV are being monitored and the measurement results analysed. This project allows valuable knowledge to be gained on the optimal interaction between system components such as the solar generator, storage unit and electric appliances.

On commission to the DAV, we are co-ordinating the technical aspects of the project with our European partners, the Austrian Mountaineering Club (OEAV) and the Spanish consumer association SEBA. The projects which have already been completed are located in the Austrian and German Alps and the Spanish Pyrenées.

* free-lance



Fig. 1: Photovoltaic modules and collector field on the south-facing roof of the Brandenburger Lodge, the highest lodge of the DAV at an altitude of 3277 metres above sea-level.

All of the mountain lodges which were equipped as part of the project are electrically autonomous systems, as they are not connected to the public grid. The photovoltaic generator supplies most of the electricity in almost all of the systems. Diesel generators or wind generators increase the supply reliability during extreme demand peaks or overcast weather periods. These hybrid systems can often meet the severe demands on electricity quality and system reliability for a lower cost than purely photovoltaic systems.

A solar power supply does not simply imply that one source of energy is replaced by another, but also includes optimising the consumer side: For instance, the electricity consumption in the Tölzer Lodge was halved by installing compact fluorescent lamps and energy-saving appliances. Since the installation of the 3 kWp photovoltaic system, about 1200 litres of diesel oil have been saved each season.

We have summarised the experience and results from EURALP in a 16-page brochure (in German). This is available from the Munich office of the DAV, www.alpenverein.de.



Fig. 2: Tölzer Lodge, at an altitude of 1825 metres above sea-level. The entire electricity demand is met by 35 m² of solar cells with a rated power of 3.5 kWp and a 750 W wind generator.

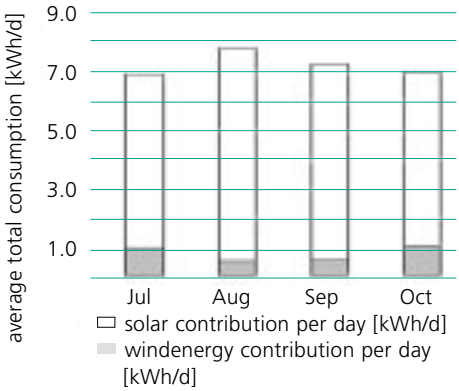


Fig. 3: Monthly electricity consumption of the Tölzer Lodge in kWh per day, from July to October. Solar energy provides 85 % and wind energy 15 % of the demand.

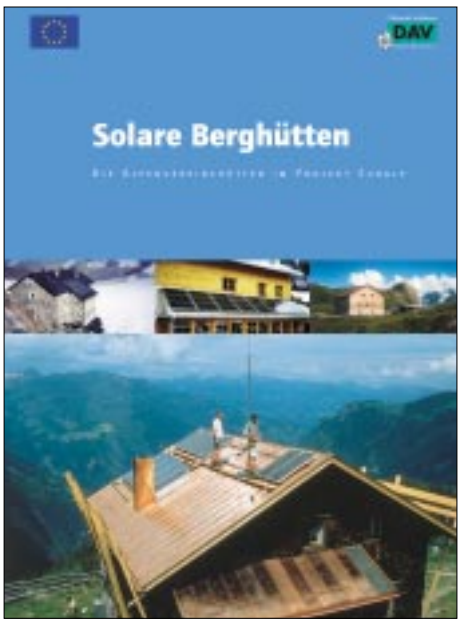


Fig. 4: Information brochure published by the DAV on the EURALP project.

Newly Installed PV Hybrid Systems in the European Alps - the EURALP Programme

Klaus Kiefer, Eberhard Rössler*

* free-lance

Many people do not yet have a connection to a public electricity grid - even within densely populated Europe. Resettlement in some areas, e.g. the southern regions of the Alps, and the desire for electricity without noise or exhaust fumes, make PV hybrid systems technically attractive and economically feasible solutions. Experience from projects in Europe can be of world-wide benefit.

In the joint European project, "EURALP", we are supporting the new installation of 17 grid-independent photovoltaic systems on mountain lodges belonging to the German Mountaineering Club DAV. We coordinate the technical side of the whole project with the European partners, the Austrian Mountaineering Club OEAV and the Spanish user association SEBA. The systems are installed by local companies. Reliable long-term operation is guaranteed by contracts with the installation companies, which carry out maintenance according to our standards. The projects which have already been completed are located in the Austrian and German Alps and the Spanish Pyrenées. The project is funded by the EU, DG XVII.

Our main tasks are:
- to prepare guidelines for the energy concepts and the system design
- to check the energy concepts of participating companies
- to authorise installed systems
- to determine quality and yield with a two-year measurement programme.

The aims of the project are to optimise the interaction between the solar generator, storage unit and electric appliances, to reduce costs and to further increase reliability.

Two positive results can already be reported now:
We have reduced the specific system costs from about DM 45,000 per kilowatt installed photovoltaic power (in 1990) to DM 30,000 by use of standardised guidelines for the energy concept and efficient planning and installation. Our technical inspections for authorisation confirm a high system quality. In all projects, the intelligent state-of-charge display (BAKO - battery control unit), which we developed in cooperation with Siemens Solar, is responsible for the energy management. In some cases, the systems are monitored via cellular phone.

name of the mountain lodge	altitude	location	PV rated power	system type	operating since
Hexenseehütte	2576 m	Austria	880 Wp	PV stand-alone	Sept 1996
Tölzer Hütte	1792 m	Austria	3520 Wp	PV/wind	May 1997
Starkenburger Hütte	1692 m	Austria	5000 Wp	PV/gas cogener.	Junei 1997
Gamshütte	1916 m	Austria	1540 Wp	PV hybrid	Junei 1997
Traunsteiner Hütte	2576 m	Austria	4400 Wp	PV/diesel	Sept 1997
Brandenburger Haus	3277 m	Austria	2640 Wp	PV stand-alone	July 1998
Schmidt-Zabierow Hütte	1966 m	Austria	2200 Wp	PV/wind	Oct 1998
Ludwigsburger Hütte	1959 m	Austria	3600 Wp	PV stand-alone	July 1998
Guffert Hütte	1495 m	Austria	1320 Wp	PV/gas cogener.	Oct 1998
Weilheimer Hütte	1955 m	Germany	1980 Wp	PV/wind	Oct 1998

Tab. 1: Completed projects for the German Mountaineering Club.
The remaining projects will be implemented in 1999.

Full-page illustration: Selection of alpine lodges, which have been equipped with hybrid systems within the EURALP programme: Starkenburger Hütte (1), Brandenburger Haus (2), Gamshütte (3), Traunsteiner Hütte (4) and Ludwigsburger Hütte (5).

Concepts for Combining Decentralised Water and Power Supply Systems based on Regenerative Energy in Rural Areas of the Maghreb Region

Rural water and energy supplies were provided only very slowly in the past in threshold and developing countries. Thus, more than one thousand million people still do not have acceptable access to water and power supplies. Energy and water supplies are closely connected to each other, as energy must be expended to pump and treat water. We co-operate with local partners to develop technical and organisational concepts which will allow water provision to be combined better with rural electrification.

Rana Adib, Christian Brennig,
Silke Drescher*, Dirk Uwe Sauer
Martin Wegmann

The technological development of off-grid, decentralised power and water supply in developing countries is an important aspect of improving living conditions in the target countries on a permanent basis. Appropriate financing and management models for the introduced systems guarantee long-term infrastructure in rural regions.

This is the starting point for the EU-funded "JARUWA" project, which we are running jointly with our Moroccan partner in the Maghreb Region. Economists and engineers are developing concepts together, which take account not only of technical issues but also organisational and financial aspects of combined rural infrastructure for water and power supply, which are based on regenerative energy. A special feature is identification of synergetic advantages which result from introducing and managing the water and power supply systems jointly.

Within the project, we have chosen Morocco as the country to be studied, as governmental programmes to improve the water supply (PAGER) and the power supply (PERG) are already running in rural areas, so that initial experience has already been gained. Decentralised supply approaches with renewable energy sources are explicitly supported in these programmes.

We compared and combined the two programmes on the basis of their classification criteria for villages which will not be connected to the national electricity grid. We used these criteria to identify suitable villages for case examples, and described their needs in more detail after conducting field investigations. At the same time, we discussed implementation and management approaches for rural water and power supplies with the responsible representatives from politics, research and economics.

The interim results revealed that water and power supplies have been introduced independently of each other in Morocco up to now. Existing synergetic opportunities are not exploited, although many criteria for the systems are similar.

There are various approaches which can be appropriate for maintaining and managing the systems. The "community management" approach, in which the users themselves are responsible for smooth running of the system, operates on different principles to the "service concept". The latter relies on the involvement of private commercially organised bodies (individuals or companies), which guarantee reliable system operation for a fee.

Our plans to use the results of the study as the basis for discussion in an international workshop, with participants from Europe and the Maghreb, have been encouraged by the considerable interest shown in our activities. The workshop aims to promote exchange of concepts and experience in the north-south and south-south directions. The results are intended to strengthen co-operation between the Maghreb States and the EU in the rural infrastructure sector, and to further promote the use of solar energy in the sunny Maghreb States.



Fig. 1: PV-powered water supply in Efert, Morocco, with an integrated disinfection plant. In future, a miniature electricity grid based on photovoltaics should also be installed in the village.

*free-lance

Clean Water with Clean Energy

At present we are demonstrating, in several pilot villages in Latin America and North Africa, that hygienic conditions can be improved cheaply and sustainably by PV-powered systems for purification of drinking water. We prepared this with detailed laboratory tests on the one hand, but on the other by carefully considering sustainable implementation of the new technology in each context. The theoretical basis for the project is the socio-technological approach, in which the introduction of new technology is supported sociologically.

Orlando Parodi, **Klaus Preiser**, Petra Schweizer-Ries, Ingo Vosseler, Lars Nupnau, Kathrin Ramsel, Christof Slickers

According to the United Nations Development Programme UNDP, 1,800 million people around the world did not have access to clean drinking water in 1997. Often, these communities do not have a connection to the public electricity grid either. The advantages of combining decentralised water purification with a photovoltaic power supply to improve the living conditions in rural areas of developing and threshold countries are obvious.

Thus, photovoltaically powered water purification systems are being installed in several pilot villages in Mexico, Argentina and Morocco, within a project funded by the European Union (DG XII, INCO-DC). Apart from Fraunhofer ISE, partners from Argentina, Mexico, Spain and the World Health Organisation are involved.

Detailed tests at Fraunhofer ISE served to assess the suitability of water purification systems with a capacity of 1 - 100 m^3/day for decentralised application in developing countries and combination with a photovoltaic power supply. We investigated five chlorinating systems, three systems which produce oxidising substances by electrolysis, and nine systems which kill off pathogenic germs by UV radiation at a wavelength of 254 nm. Only a few systems met the requirements.

With the help of local technical and sociological partners, we made systematic enquiries in the pilot villages: water quality and energy supply, demographic data, current water consumption, knowledge structures and behaviour patterns, which are directly related to the water supply.



Fig. 1: A UV reactor is tested in the laboratory.

Detailed knowledge of the local situation allows the water supply to be planned appropriately for the different villages: In Balde de Sur de Chucuma, in Argentina, the existing well in the village centre was equipped with a chlorination system, which is powered by two 40 W_p solar modules and can disinfect about 4 m^3 of drinking water each day. In the school, a UV system powered by a 50 W_p module provides children, teachers and neighbours with about 1 m^3 of disinfected drinking water each day. In the Mexican village of San Antonio, the local spring water is purified by an electrolysis cell, which is powered by a 50 W_p solar module.

Although biological tests of the water and prevailing illnesses prove that pathogenic agents are transmitted by the drinking water, only a small proportion of the affected villagers consider it necessary to treat their drinking water. For this reason, we take various measures to raise awareness, e.g. by instruction sessions in the schools. In addition, other aspects of the water supply are improved in the pilot villages together with the quality of the drinking water.



Fig. 2: Water is traditionally drawn by hand from open wells in Balde de Sur de Chucuma. Opportunities for contamination are manifold. The solar-powered purification systems introduced by Fraunhofer ISE ensure that the drinking water is clean.

Photovoltaics against *E. coli.* Bacteria

Sterilisers for drinking water are being tested at Fraunhofer ISE with regard to their combination with photovoltaics in developing countries.

O. Parodi, M. Preikschat, **K. Preiser**, I. Vosseler

The statistics of the World Health Organisation speak for themselves: About 50 % of the population in developing countries does not have any access to clean drinking water and about 80 % of all diseases there can be traced back to poor-quality water supplies. This was reason enough for the group, "Rural Electrification", at Fraunhofer ISE to tackle this subject. How can solar energy be used to purify water in remote areas? One possibility is with small sterilisation units, based on UV C radiation or on anodic oxidation, which is powered by a small photovoltaic system.

It must be observed that both photovoltaics and the specific boundary conditions in developing countries place additional demands on such systems. For this reason, Fraunhofer ISE is testing sterilisation units from European manufacturers for their suitability for photovoltaically powered operation. Interesting results: Effective sterilisation does not necessarily need much energy. The UV technology only needs 100 Ws/l even for strongly contaminated water. With anodic oxidation, the energy consumption can be reduced further to about 30 Ws/l. Operational reliability poses more of a problem: Whereas there are no safety components for anodic oxidation and they would be difficult to integrate, the weakness of UV sterilisation is the limited lifetime of the UV source of about one year. In addition, during the tests it became evident that some of the devices which have been approved for the German market do not fully comply with the valid standards and guidelines, particularly those concerning user protection if the sterilisation is not completely effective. Improvements must be made in this respect before Fraunhofer ISE installs two drinking water sterilisers, which are adapted to the local conditions and photovoltaic operation, in Latin America as part of an EU project.



Fig. 1: Test stand for drinking water sterilisers.



Purification of Drinking Water with Photovoltaics for Remote Areas

Systems and methods to purify drinking water are available all over the world. Despite this, about 5 million people die every year from diseases which are transmitted via drinking water. Together with partners from Latin America and Spain, we have developed approaches for purifying drinking water and implemented them in five pilot villages.

Orlando Parodi, Klaus Preiser, Petra Schweizer-Ries



Fig. 1: Clean drinking water cannot be taken for granted in developing countries.



Why, when water treatment with chlorine, ozone and UV radiation is widely known, are there still about two thousand million cases of diarrhoea each year caused by drinking water? We started the EU project on "Clean Water with Clean Energy" with this question. Surveys in Morocco and 10 Latin American countries revealed the following information:

- In rural regions of developing countries, drinking water is often drawn from surface sources which are anthropogenically polluted.
- This water is usually not disinfected before consumption. From the consumers' perspective, the hygienic aspects of drinking water are secondary to taste, supply reliability and convenience.
- Rural regions often lack not only intact drinking water and sewage systems, but also electricity.
- Regulations on drinking water quality exist in almost every country of the world, but they are seldom enforced in rural areas.

Commercially available chlorination systems, UV devices and systems based on the principles of anodic oxidation or microfiltration were all deemed to be fundamentally suitable for the boundary conditions listed above, but none of the tested systems could meet all the necessary specifications. Thus, we developed new, appropriate, PV powered systems. Finally, five different, energy-optimised systems were installed in five villages: Different dosing systems for sodium hypochloride, an electrolysis cell to produce chlorine gas and a UV system.

Fig. 2: San Antonio de Agua Bendita in Mexico: Disinfection of drinking water using a PV powered electrolysis cell.

The fact that the inhabitants of most of the pilot villages now actually consume hygienically acceptable drinking water results from the interaction between the new technology and non-technical factors:

- At the beginning of the project, there was already a desire for clean drinking water or it was aroused by health education.
- Negative effects of disinfection, such as a change in taste, were largely avoided.
- The introduced technology was robust, easy to handle, largely automated and required little maintenance. Responsible persons were involved at the village level and within the appropriate government bodies.

After two years of operation, all of the systems are functioning reliably, without any breakdowns.

The results of the project on "Clean Water with Clean Energy" demonstrate that photovoltaically powered systems can make an important contribution towards supplying rural areas of developing countries with hygienically acceptable drinking water, if the technology and the introduction methods are chosen appropriately. We will therefore continue to develop such systems and methods to introduce them.



Product Development of a Photovoltaically Powered Water Purification System

One thousand million people are living without access to electricity or clean drinking water. Water purification technology must be adapted to the conditions in regions remote from the grid if these people are to have a sustainable supply of drinking water.

Jochen Benz, **Georg Bopp**,
Markus Brandl, Orlando Parodi,
Ulrike Seibert, Andreas Steinhüser

In rural areas of developing countries, there is often neither a connection to a public electricity grid nor a supply of clean drinking water. Off-grid, decentralised systems are suitable to supply hygienically acceptable drinking water to these areas. We therefore develop concepts for photovoltaically powered systems for purifying drinking water.

Together with the SolarFabrik GmbH, we developed a stand-alone water purification system specially for application in developing countries.

During field investigations in Morocco, one of the target countries, we found out that potential customers wanted a combination of water pumping and water purification. These two features of the system led to the product name, WATERpps (water pumping and purification system).

The basic concept of WATERpps has the following elements:
- pumping of domestic water and purification of drinking water
- water supply for 25 to 50 persons
- drinking water purification by microfilters from Katadyn, Switzerland
- stand-alone photovoltaic power supply
- compact and robust construction
- user friendly
- cheap to produce

In implementing it, we observed the conditions in detail where the system will be used. For instance, the WATERpps prototype has excellent features concerning transportability. The compact housing unit allows the system to be transported safely to the planned installation site, which may well be very remote. The hinged construction makes installation simple. A microbiological risk for the drinking water can arise only if the filter is subjected to stagnation conditions for longer periods (risk of clogging growth). An active protective device warns against this state. Automatic pump switch-off and a simple energy storage display prevent energy from being wasted.

During the product development process, we carried out various long-term tests of the system. To this purpose, we set up a universally applicable test stand for water purification systems. We can use it also to characterise other types of water purification systems.

The work was funded within the BMWi programme on "Photovoltaics for appliances and small systems."

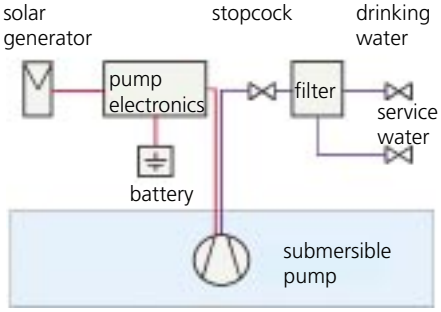


Fig. 1: System diagram of WATERpps.



Fig. 2: WATERpps prototype.



Fig. 3: The WATERpps prototype ready for transportation.

Mineralisation and Disinfection to Obtain Drinking Water from Seawater

We develop procedures to prepare drinking water. The subject of the SODESA project is a solar powered desalination system for seawater. This system prepares about 600 l drinking water per day by evaporation at atmospheric pressure, condensation and subsequent treatment. The novel features are a thermal storage tank, which is filled from seawater-resistant collectors developed specially for this purpose (see p.27), and a mineralisation and disinfection unit.

Florian Edler, **Orlando Parodi**

Must distilled water be mineralised?

Drinking larger quantities of distilled water is harmful to humans. It leads to excessive water uptake by cells in the body and can dissolve heavy metals in distribution piping. On ships, desalinated water is either passed through mineral filters or treated with solid salt additives. By contrast, in the low-maintenance SODESA system (fig. 1), a controlled amount of seawater is added to the distillate from the desalination unit via a membrane pump.

Is further treatment needed?

Disinfection after mineralisation guarantees the biological quality of the drinking water prepared in the SODESA system: The desalinated and remineralised water is radiated with UVC light at a wavelength of 253.7 nm. The final product is high-quality drinking water which conforms to European standards.

Where does the energy come from?

A photovoltaic system with a system voltage of 24 V, a 106 Wp solar generator and a storage battery with a capacity of 75 Ah supplies power not only to the mineralisation and disinfection unit, but also for pumping the water from the desalination unit outlet to an elevated reservoir.

How do the individual components interact?

The desalination unit produces distillate continuously, 24 hours a day. By contrast, the subsequent process steps operate discontinuously to optimise the energy and economic performance: The distillate is collected in a retaining tank and the pumped through the mineralisation unit into the elevated reservoir (fig. 2). The disinfection unit operates whenever there is a demand for water. A 50 l buffer tank supplies water during the time gap after turning on the tap, before the UV system is ready for operation.



Fig. 1: The SODESA mineralisation and disinfection unit in the test stand at Fraunhofer ISE.

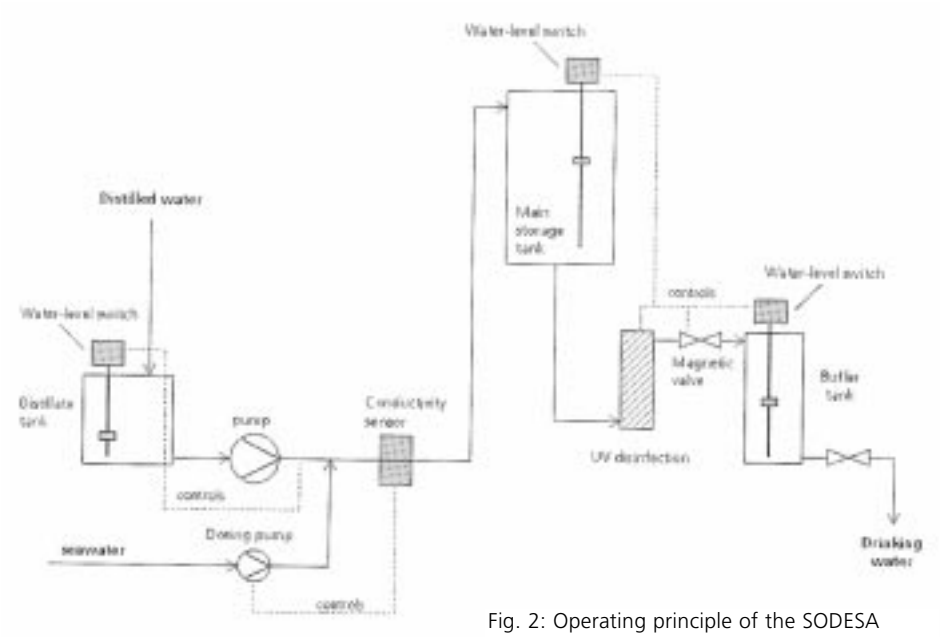


Fig. 2: Operating principle of the SODESA mineralisation and disinfection unit.



Collector with a Corrosion-Free Absorber for Desalination of Seawater

We have developed a collector in which hot seawater (90 °C) can flow directly through the absorber.

Matthias Rommel,
Joachim Koschikowski*,
Michael Hermann, Arim Schäfer

The absorber consists of glass tubes (16 mm external diameter) with a selective absorber coating and feeder pipes of reinforced silicone. A zigzag pleated reflector is mounted under the absorber so that the aperture area of the collector is used efficiently. Figure 1 shows a sketch of the collector configuration, fig. 2 a photo of the collector. The absorber construction is such that a large-area module with external dimensions of 1.5 m x 4.8 m can be built.

We produced eight collector modules in our own workshop as a pilot plant for the SODESA seawater desalination project on Gran Canaria, which is supported by the European Union. The system (fig. 3) was installed on Gran Canaria in May, 2000 and taken into operation. It applies the Multi-Effect Humidification (MEH) process for distillation. The collector field with the 8 collectors has an aperture area of 47.2 m^2. A building can be seen behind the collectors. It houses the 6.3 m^3 storage tank for 90 °C hot seawater, the distillation unit and a photovoltaically powered water purification unit with mineralisation and UV sterilisation. The system is dimensioned for a daily production of 600 l drinking water in very good quality.

The new collectors with the corrosion-free absorbers have proven themselves well. They can be used universally in all thermally powered seawater desalination processes or to heat the inlet water in desalination units based on reverse osmosis.

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg

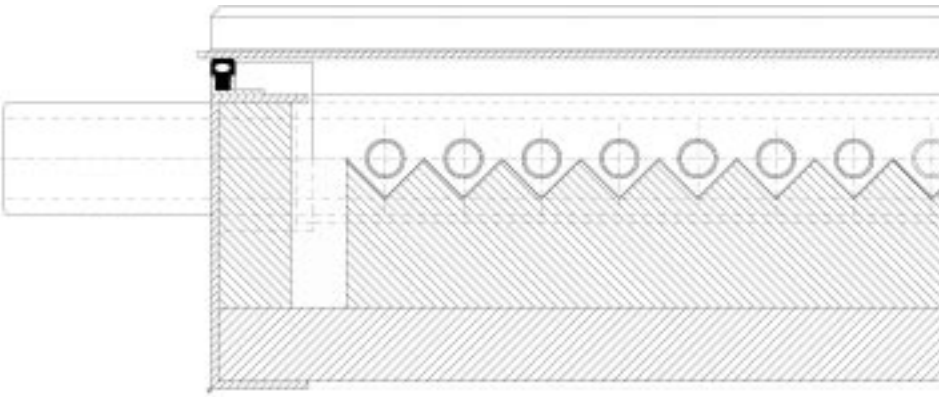


Fig. 1: Construction of the SODESA collector. A zigzag pleated reflector is located below the absorber tubes (circles).

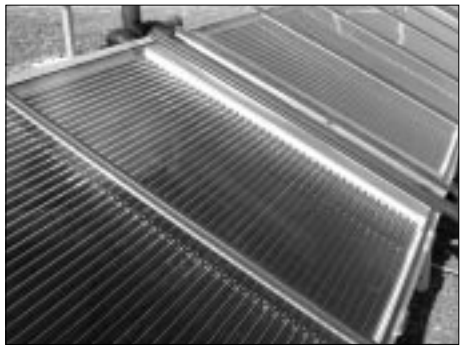


Fig. 2: The reflections from the folded edges of the reflector can be seen as bright lines parallel to the collector tube axes.



Fig. 3: SODESA collector system on Gran Canaria.

Development of Corrosion-Resistant Collectors for Seawater Desalination - SODESA

We are developing novel collectors, through which hot seawater at a temperature of 80 °C can flow without any risk of corrosion. We make use of polymers and ceramic materials.

Matthias Rommel,
Michael Hermann*,
Joachim Koschikowski, Arim Schäfer

Fig. 1: SODESA logo.

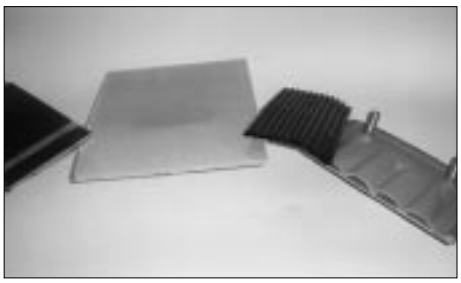


Fig. 2: The photo shows four of the seven different corrosion-resistant absorber constructions which were investigated in the course of developmental work.

The aim of the international SODESA project is to construct and operate a solar thermal seawater desalination system in the Centro de Investigación en Energía y Agua CIEA in Pozo Izquierdo, Gran Canaria. The system is intended to supply 600 litres of desalinated water in good drinking quality each day. It will be installed in May 2000. The EU is supporting this project, which we have been leading since July 1998 and in which we are developing solar collectors with novel, corrosion-resistant absorbers. We make use of polymers and ceramic materials. Depositing the selective coating on the new materials, and withstanding the high absorber stagnation temperatures, represent the main challenges in this successful development. A collector area of 40 m^2 with this new absorber will be constructed as eight 5 m^2 modules for the pilot plant in Pozo Izquierdo. In addition, we developed the systems to purify the desalinated water to drinking water quality for the project (see p. 67).

The project also demonstrates that new materials open up new potential for development. We have gained valuable insight into the application of polymer materials in collectors.

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg



Rural Energy Supply Models - How can Rural Customers be Reached?

A basic question for market-orientated rural electrification is how to bring the power supply systems and services to the final customers. We have categorised and characterised marketing and infrastructure models as a service to industry, government institutions and financing agents.

Rana Adib, Klaus Preiser

Renewable energy is viewed as a good and natural solution to supply energy to rural households in developing and threshold countries. The key actors have now chosen a market-orientated approach for providing energy to the population which does not yet have access to electricity - more than two thousand million people around the world. As not much experience has been gained yet with such large projects, there are still numerous issues to be clarified.

We co-operated with the International Solar Energy Society ISES to produce the widely noted study on "Rural Energy Supply Models (RESuM)". Its aim is to support actors such as governments, businesses and financing institutions in their activities concerning rural electrification.

The study fills gaps in knowledge of appropriate power supply models for rural areas in developing countries. It provides information about establishing the various distribution and dissemination models and summarises experience with these models. The information is available in a structured form at a specially developed Internet site.

A market-orientated and market-controlled approach can be combined with sustainable electrification politics with the help of the study. The results allow us to advise companies and financial institutions during the market introduction phase, and to work with them in preparing the optimal marketing strategy.

The following model categories were identified and defined: cash, credit, leasing and service. The reader is offered a structured overview of the corresponding power supply models, their characteristics, advantages and disadvantages. Information is provided about contractual agreements between the system and/or service provider and the final customer. The study also investigates business procedures such as advertisement and installation. The structured analysis is supported by practical examples for each type of power supply model.

As an example, we present results from the "fee for service" model in the following section (fig. 2).

In the "fee for service" model, the customer pays a regular contribution for an agreed, fixed energy service. The service price is determined by the hardware costs plus dealers' margins, financing costs and costs for installation, insurance and maintenance. Infrastructure is necessary for sales, installation, maintenance and insurance. The models assumes long operating periods.

The following problems and risks arise for the service provider:
- high costs for the infrastructure
- repair costs and the question of responsibility in the case of system failure
- storage of spare parts for long periods of time
- lack of technical facilities to monitor overuse by the customer.

Nevertheless, the "fee for service" model has a very high potential for opening markets also among poor households, as the customers are not burdened with high initial investment costs.

The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety funded the study.

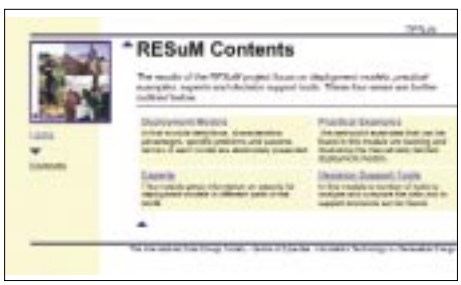


Fig. 1: Interactive Internet site (http:\\resum.ises.org)

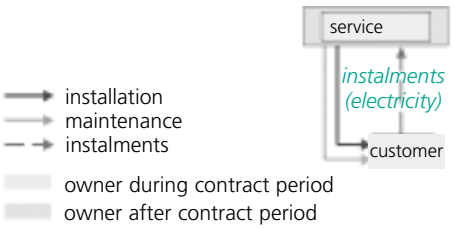


Fig. 2: "Fee for service" model for operation and financing.

Micro-Finance - Innovative Marketing Concepts for Rural Electrification

Micro-finance is a component of innovative marketing concepts which we design for the constantly growing markets in rural electrification in developing countries. In doing so, we support commercial enterprises, for whom the photovoltaic projects must be financially sustainable and profitable.

Rana Adib*, Klaus Preiser



Fig. 1: Authorisation of a group credit in a village bank run by the credit acceptors in Quillacollo, Bolivia.

We develop marketing concepts as examples accompanying the introduction and dissemination of photovoltaic systems for rural electrification, which stimulate the interest of commercial investors such as module manufacturers or electricity utilities. As part of this work, we have investigated the opportunities and potential of micro-finance in cooperation with the Fraunhofer Institute for Systems Technology and Innovation Research ISI. The primary premise is involvement of micro-financial institutions (MFI's) as financial intermediaries.

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg

What is micro-finance?

Micro-finance is provision of financial services to the low-income population of developing countries who do not dispose of conventional collateral and thus do not have any access to the formal financial sector. Typical providers such as credit cooperatives, non-governmental organisations or savings societies have developed new methods: Repayment of credits is ensured by instrumentalising social mechanisms, e.g. peer group credits, but also appropriate economic evaluation of the borrowers.

As instalment payment schemes for photovoltaic systems become more widespread, MFI's represent a chance to reduce the high collection risk.

What did we investigate?

Our aim was to identify the role and potential tasks of MFI's in rural electrification. We have analysed various approaches, methods and institutions for micro-finance both theoretically and in practice in Morocco and Bolivia. In a further step, we questioned some potential international investors to determine their strategies in conjunction with the dissemination of photovoltaic systems in developing countries. On this basis, we have classified MFI's and investors, identified relevant combinations of the classes and developed marketing concepts as examples.

The role of micro-financial institutions

The fundamental advantage of MFI's in photovoltaic projects is their expertise in securing the repayment of credits. Their intrinsic role is therefore to organise and guarantee the payments by photovoltaic customers. In addition, involvement of these institutions offers better boundary conditions for monetary transfer between photovoltaic customers in the villages and photovoltaic suppliers in the city.

The dissemination of photovoltaic systems on a credit basis has benefits for small and medium-sized enterprises, particularly in cooperation with formal MFI's, as the preliminary financing of the systems is assumed by the financial institution in the form of "electricity credits".

Sociocultural structures are fundamentally integrated into the approach of MFI's. This facilitates not only contact to potential customers, but also access to information on the target group. Simultaneously, it opens up new information, communication and distribution routes for the photovoltaic investor.

Outlook

IIn our study, it became evident that cooperation with MFI's represents a chance to implement integrated infrastructure projects, e.g. which combine photovoltaic electrification with solar water supply and treatment.

Economic Investigation of PV Hybrid Systems - Analysis and Optimisation Calculations

After analysing the maintenance demand and investment costs of 30 PV hybrid systems, we were able to document the real costs in detail. Using a complex design and optimisation program, we are now able to calculate the most economic system for any power supply task, taking all technical and economic boundary conditions into account.

Georg Bopp, Georg Hille, Hans-Georg Puls*, Dirk Uwe Sauer, Martin Schulz

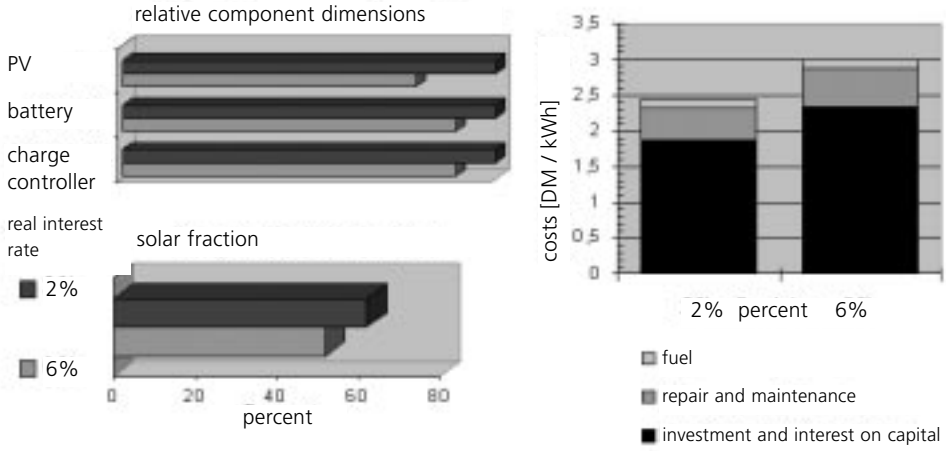


Fig. 1: Electricity generation costs according to the annuity method and relative component dimensions for two cost-optimised PV-diesel-battery systems located in Freiburg, with a consumption of 11,000 kWh/year, for real interest rates of 2 % and 6 % (PV generator lifetime: 20 a).

Our analysis was based on a comprehensive survey of 30 PV hybrid systems, each consisting of a PV generator, charge controller, battery, diesel generator and inverter, with a total of 150 operating years, which was funded by the German Federal Ministry of Economics and Technology BMWi. By combining these results with current ordering information, we were able to determine the installation and maintenance costs of this type of system. Maintenance contracts with local electricians and an analysis of the frequency and cost of repair work were the primary sources for the investigation. The results were that the total electricity generation costs per consumed kWh electricity, taking investment, maintenance, replacements, repairs and financing costs into account, were between 3 and 30 DM for these systems. Costs at the high end of the range occur in systems which are used only seasonally. There is a strong correlation between the annual electricity consumption and the cost per kWh.

We have developed a complex simulation and optimisation program applying powerful technical lifetime models. It allows systems to be designed with consideration of a wide range of boundary conditions, with economic viability playing a central role. Lifetime simulations are made for the whole system and all of the costs which occur for individual components are calculated. The effect of operation management on the energy flows and component lifetime are also taken into account. For each power supply task and each set of boundary conditions, the optimal system configuration and operation management are calculated with a non-linear optimisation algorithm, and the costs are compared.

The number of parameters used in such a calculation is too large to be discussed in detail in the present context. Nevertheless, some essential points about the electricity generation costs for a stand-alone system in Freiburg can be stated here:

- With an annual consumption of 11,000 kWh, costs of 3 DM/kWh can be achieved in the best case. For 1,500 kWh, the cost is 6.50 DM/kWh.
- For a consumption of at least 15,000 kWh/year, a PV hybrid system is always more economic than a diesel-battery system.
- Halving the price for the PV module reduces the total costs by only 10 %.
- A system with the same specifications at a site in Mexico would cost about 10 % less.
- The interest rate on capital is the most significant factor determining the electricity generation costs (fig. 1).

Figure 1 shows the costs, design dimensions and solar fraction for two different interest rates. It illustrates that the dimensions of capital-intensive components in a cost-optimised system will be smaller for the higher interest rate than for the lower one. The higher the interest rate, the more economic is electricity generation with diesel fuel, where the costs are incurred gradually throughout the system lifetime.

* free-lance

Grid-Independent Photovoltaic Systems - Minimal Costs by Optimal Maintenance

The assertion, that grid-independent photovoltaic systems are free of maintenance under all conditions, is correct only with regard to the solar generator. All other components require - like every complex, technical system - repairs, improvements and regular maintenance work to an extent which is not yet fully known. Improved operation control strategies reduce these operating costs and thereby help the user.

A. Armbruster, **G. Bopp**, R. Kaiser*, H. G. Puls, M. Rehm, D. U. Sauer, M. Schulz

In around 20 selected photovoltaic systems, which were originally constructed by Fraunhofer ISE for the German Mountaineering Association (DAV) among others, local companies make annual inspections. We have prepared model maintenance contracts and handbooks and instruct the companies in their duties. In 1996, maintenance work was done on 14 stand-alone systems, and in parallel, log books recording any disturbances and the energy meter values are kept, for these and seven additional systems. The Institute analyses the maintenance costs and causes of breakdown, prepares statistics on operation interruptions and determines the optimisation need for components and the whole system. Detailed statistics on interrupted operation are not yet available, as the maintenance work only started in 1996. However, a preliminary review shows that a defect, which the user cannot repair, occurs on average about once a year. Often these are small matters such as burnt out fuses, but defects also occur in technically immature components.

The users are often dissatisfied with the low level of automatisation in system operation control, particularly with regard to the battery. On the short term, this leads to reduced use of the available energy supply, and on the long term to a shortened battery lifetime. The two following examples will illustrate the subject of operation control.

Weather prediction:

We are investigating the effect of a planning operation control system with the help of dynamic optimisation. It can make better use of the capacity of an energy storage unit on the basis of weather forecasts. For instance, it postpones energy services which are not urgent during periods of overcast weather. Thus, a smaller storage unit can provide the same degree of user comfort.

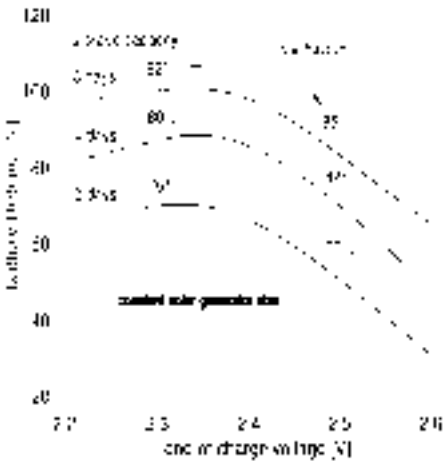


Fig. 1: Battery lifetime as a function of the end-of-charge voltage and the storage capacity.

Battery aging:

Batteries often age prematurely because fixed battery voltage values are used as the control quantity. This does not allow specific battery management, so deep discharge and insufficient charging result. We are therefore working on better algorithms to estimate the state of charge and on models for battery aging under real operating conditions. As an example for such model design, fig. 1 shows the dependence of the battery lifetime on the end-of-charge voltage for different storage capacities. This knowledge allows the operation control and system dimensioning to be optimised. Because of the numerous variable parameters and the poorly defined aging processes, we use genetic algorithms and fuzzy logic theory as tools.

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* free-lance

Dynamic Electricity Rates in Regenerative Power Systems as a Means of Operation Control

In remote areas, a power supply from regenerative energy sources is often less expensive than a connection to the public grid, which may also cause damage to sensitive ecological systems such as the Alps. The German Alpine Club (DAV) has therefore cooperated with Fraunhofer ISE to equip more than ten lodges with photovoltaic systems, including the Rotwandhaus with 100 beds.

G. Bopp, **M. Rehm**, E. Rössler

Energy-saving appliances were introduced at the same time as the regenerative energy systems. Sufficient energy was thus available at the Rotwandhau, free of charge. This resulted in less attention being paid to the rational use of energy.

More appliances were acquired. The result is poor matching between the solar supply and the energy demand, and increasing electricity consumption. Thus, measures to control the consumption are also needed after a regenerative energy supply system has been installed.

The appropriate form of load matching to the energy resources depends strongly on the individual type of household appliance. For example, it is more practicable to postpone the use of a washing machine than of a dishwasher. Load matching can be achieved either with the help of technical measures or by a change in consumer behaviour.

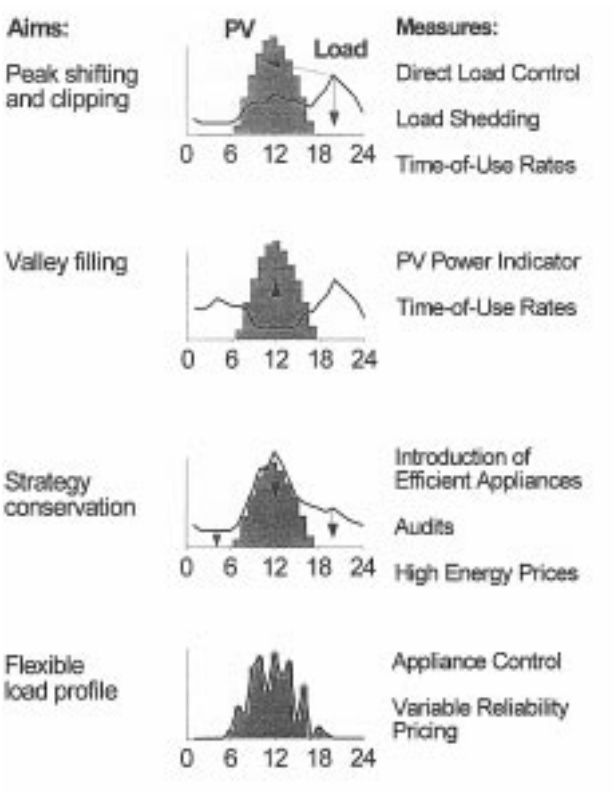


Fig. 1: Possibilities for load optimisation in photovoltaic applications.

Many autonomous electric power supply systems already include technical devices to regulate the load. One type is simple peak-load monitoring or load locking, sometimes combined with timers. In the load-locking approach, the individual appliances are divided into groups. Each group is disconnected from the circuit at a given total load corresponding to its priority. In the Rotwandhaus, a load-locking system with three groups has been installed. However, technical load management does not necessarily change the consumer behaviour. On the contrary, resistance can be expected if the reasons for switching off appliances are not obvious or general operation is disturbed.



Fig. 2: The Rotwandhaus is equipped with a 5 kW_p solar generator, a 20 kW wind turbine and a battery with a capacity of 65 kWh. A 30 kW diesel generator serves as a back-up. The electricity rate fluctuates as a function of the available resources between 0 and 2 DM/kWh. The current value is displayed to the users.

A complementary or alternative measure is a dynamic electricity tariff with a variable electricity rate. It was introduced in May 1995 to the Rotwandhaus on a trial basis after consultation with the DAV. A display in the kitchen shows the electricity rate, which varies from 0 DM/kWh to 2 DM/kWh, depending on the resources available. The proceeds should cover the cost of new batteries in future. The price was calculated such that the residents will benefit financially if they use their appliances at appropriate times.

It was important to ensure acceptance by the residents of the Rotwandhaus, as energy consumption has hardly been associated with any costs up to now. Adaptation of the consumer behaviour to the currently valid price can already be identified.

At the same time, the tariff trial also provides a basis for possible technical improvements in load matching, such as:

- lower battery stress with longer cycles or reduced deep discharge
- reduction of the number and duration of diesel operation periods
- use of excess energy when the battery is fully charged.

Factors for Successful Use of Photovoltaics in Houses and Villages Remote from the Grid

For more than 10 years, we have been working on PV hybrid systems to supply power to European houses and restaurants at locations remote from the grid. In 1999, we collated the technical, economic and sociological insight we have gained over 150 operating years to make the factors for success generally accessible.

Rana Adib*, Georg Bopp, Esther Burkhard, Klaus Preiser, Dirk Uwe Sauer, Martin Schulz, **Petra Schweizer-Ries**, Birgit Uenze, Sebastian Will

A total of 30 stand-alone PV systems for different applications were intensively controlled. The main aspects of interest were the improvement in reliability achieved by introducing maintenance contracts, the frequency of remaining faults and the resulting operation costs. At the same time, we analysed the development of the energy demand over the years and the solar fraction or the proportion of auxiliary energy supplied e.g. by diesel generators.



Fig. 1: Information display for the Spanish company, Trama Tecnoambiental, being tested at Fraunhofer ISE.

We have developed a complex simulation and optimisation program, which draws on a comprehensive survey of a total of 150 operating years funded by the German Federal Ministry of Economics and Technology BMWi, and applies powerful models for technical lifetime prediction. The program allows a wide range of boundary conditions, above all the economic viability, to be taken into account for system dimensioning.

Consideration of the people who use the technology has been a topic in our work on "Rural Electrification" for many years, particularly in the introduction of Solar Home Systems in developing and threshold countries.

A project funded by the EU has now enabled us also to collate the knowledge of engineers, sociologists and economists on larger PV hybrid systems. Ten systems each in Spain and Germany, which demonstrably operate very well to the complete satisfaction of their users, were intensively investigated in cooperation with Spanish partners. The spectrum ranges from private houses through commercially used systems to village power supplies.

To determine the success factors, we used comprehensive questionnaires and standardised surveys of the users and maintenance companies on site as well as expert interviews. We complemented the qualitative and quantitative analysis of these questionnaires by detailed technical surveys. Our results showed that no two systems were identical, even when the same technology had been used. The systems operate reliably if they are inspected at least once a year and the operators react "correctly" to the one or two disturbances which occur on average each year. About half of these faults can be corrected by the users, who gain some technical knowledge over the years, either alone or with the help of advice by telephone. A maintenance company helps with more serious technical difficulties.

The displays indicating operating conditions had a very high priority for the users (fig. 1). There is still considerable potential for improvement in this area: The displays must provide the most important information about the current state of the system and should be easier to understand.

An important conclusion is: A technical system can only be evaluated in connection with its application. Already during the dimensioning phase, the designers should know e.g. whether the system is being operated primarily under ecological aspects or with high expectations regarding the electricity supply and reliability, as is often the case for restaurants. Our calculations indicate that system dimensioning which is appropriate to the needs of the user can save a considerable proportion of overall costs.

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg

Socio-Technical Analysis of Solar Home Systems - Indonesian Programme for 1 Million Homes

Solar Home Systems are simple, autonomous photovoltaic systems. They can provide the basic electricity supply, e.g. for lighting and radios, in regions without an electricity grid. Fraunhofer ISE supports rural electrification programmes in various ways, including sociological investigations and quality assurance. Indonesia has recently started the largest programme of this type in the world.

Jérôme Kuhmann, Tomislav Paradzik, **Klaus Preiser**, Dirk Uwe Sauer, Petra Schweizer-Ries

In Indonesia, 23 million homes are not connected to the public electricity grid. As a result of the geographical structure - the Republic of Indonesia consists of 7600 islands - grid expansion is restricted not only by economic but also technical limits. To solve this problem, the Indonesian government has initiated the largest programme in the world for rural electrification with photovoltaics, the 50 MW programme. Within the next 10 years, one million households are to be equipped with Solar Home Systems (SHS) for their basic power supply. Financed by the Federal Ministry for Education, Science, Research and Technology BMBF, Fraunhofer ISE and TÜV Rheinland are supporting this Indonesian governmental programme in setting up infrastructure for quality assurance of components and systems and investigating existing SHS programmes technically and sociologically. The Indonesian partner is the national Technology Ministry BPPT and its energy laboratory LSDE.

After establishment of the first pilot village, Sukatani, in 1989, the Indonesian President Suharto initiated the introduction of more than 3000 SHS in 14 different provinces, a programme known as BANPRES-LTSMD. This programme is based on the village cooperatives, KUD's, which exist throughout the whole country. The Indonesian government supports the growth of KUD's to improve the economic situation of the villagers - e.g. by bulk purchase of seed grain and fertiliser or marketing of the agricultural products from the villages. A "Solar Home System" section within the BANPRES-LTSMD programme is expected to take on the following responsibilities: maintenance, procurement of spare parts, repair of the PV systems, collecting the monthly rates - each family must pay 7500 rupiahs, about 5 DM/month - and reporting on the project's progress to the provincial and federal governments.



Fig. 1: Fraunhofer ISE employee during a field visit for socio-technical investigation of Solar Home Systems in Donggala Province on Sulawesi, Indonesia.

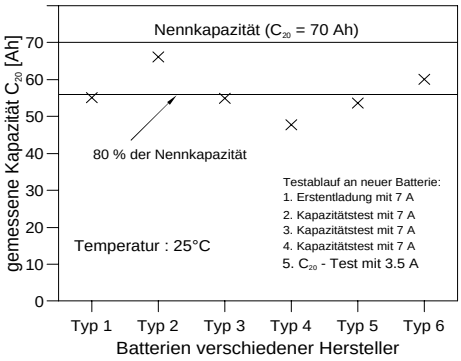


Fig. 2: Comparison of the measured capacity of Indonesian batteries with the rated capacity specified by the manufacturer for different charging/ discharging cycles. Most batteries reach only 80 % of the rated capacity even when new.

Last year, scientists from Fraunhofer ISE and BPPT/LSDE visited BANPRES projects in Sulawesi, Lampung and West Java, to ask users, village technicians and KUD's about their experience with the PV systems and to investigate the technical quality and operation of the systems. It became evident that the user satisfaction varied widely. The main complaints were that the promised service for system maintenance and repair was not available, that there was no further financial support for buying replacement parts and that the users had to pay for the systems, although it was a presidential aid programme.

From a technical perspective, it became clear that:

- sometimes newly developed components like charge controllers were used, which were not technically mature,
- often the charge controller was not optimally adapted to the batteries, with the result that many users shunted out the charge controller,
- the locally produced batteries were often far from fulfilling the specified characteristics (fig. 2), and clear aging effects appeared after only a few cycles.

The overall impression was that BANPRES-LTSMD is very well conceived and structured. However, the reaction to difficulties, such as use of low-quality components, arrears in the agreed monthly payments and migration of trained village technicians, is not yet adequate. The results of these and other investigations, such as detailed analysis of the technical quality of locally produced batteries, charge controllers, lamps, etc., will be input into current discussions on establishing an accredited test laboratory to certify Solar Home Systems at BPPT/LSDE. In the same way, the investigations provide the basis for extending the "Management Information System", which was set up as a permanent auxiliary to the 50 MW programme.

In this way, Fraunhofer ISE and TÜV Rheinland are able to provide the Indonesian government with an efficient tool for quality control. This helps to ensure that the funding is used optimally to achieve the aims of the programme.

The New DC Laboratory and the Quality of Solar Home Systems

A Solar Home System (SHS) typically consists of a solar module, a charge controller, a 12 V storage battery and DC appliances. By now, about a million such systems have been installed around the world to provide electricity to isolated houses in remote areas, and the number is growing rapidly. Accounting for about 14% of the global module production, solar home systems represent a very promising market for photovoltaics.



Fig. 1: Quality specifications for solar home systems and their components.

H. Gabler, G. Hille, R. Homa, J. Kuhmann, O. Parodi, **K. Preiser**, R. Reimelt, W. Roth, P. Schweizer

In opening up commercial markets, reduction of the investment costs is usually of primary concern. As the photovoltaic module represents the largest single investment, scenarios to reduce its manufacturing cost are most frequently discussed. However, if the costs are regarded from the viewpoint of a long-term power supply service, the picture changes dramatically. The costs are then dominated by the share for maintenance, repair and replacement. As an example, batteries often last only two years - an indication of poor quality and inappropriate charge control. In addition, lamps, radios or television sets are seldom specifically suited for SHS. Together with a network of European partners in research and industry, Fraunhofer ISE is attempting to establish suitable quality recommendations (fig. 1) and their regulation. Diverse non-technical aspects also have to be considered in this process. Fraunhofer ISE thus formed an interdisciplinary working group consisting of technical, sociological and economic experts to solve this problem.

A European market overview of DC appliances was already published by Fraunhofer ISE in 1994. A detailed test of the charge controllers available on the German market for solar home systems revealed that extreme differences in quality can also be found for these products, which often bear no correlation with the price of the components. The new and well-equipped »DC laboratory« (fig. 2) is available from now on for contract investigations on DC components for interested parties from any country.

Corresponding know-how can also be transferred to institutions in developing countries, so that they can provide the technical back-up to electrification programmes. In cooperation with industrial partners, the potential for further development of products can be determined.



Fig. 2: Part of the new testing and development laboratory for DC components (DC laboratory).

PV Test Laboratories in Developing Countries - Support for Quality Assurance and Market Development for PV Systems

Enormous potential is predicted for photovoltaics in the electrification of remote rural areas. Market development can and will be successful only if industrialised and developing countries cooperate closely. Establishing local expert centres is seen to be decisive.

Jérôme Kuhmann, Tomislav Paradzik*, **Klaus Preiser**, Dirk Uwe Sauer

Until only a few years ago, the discussion on photovoltaics for rural electrification was dominated by pilot and demonstration systems, which were financed by bilateral or multilateral cooperation. Today, the situation has changed fundamentally: Many countries have launched major programmes on rural electrification which are explicitly based on photovoltaic systems, e.g. Morocco, Indonesia, India, China or Argentina.

The involvement of national and international investors such as the World Bank, oil concerns, electric utilities, banks and insurance companies has grown parallel to this development. Expected returns, risk minimisation, permanent energy services and infrastructure development are the topics which dominate the current discussion.

* PSE GmbH – Forschung, Entwicklung, Marketing, Freiburg

Due to our interdisciplinary approach, which combines technical expertise with sociological and economic competence, we are able to support this market development in many different ways.

The quality of photovoltaic systems and their components is a decisive factor for their sustainable dissemination. The market development can only be successful in the long term if investors gain confidence in the capabilities of this new technology. Definition of national and international standards, establishment of local expert centres, building up infrastructure for installation, maintenance and operation of systems, production quality control and authorisation measurement procedures on site - these are all aspects contributing to quality assurance.

Our team from Fraunhofer ISE accompanies companies and institutions in further development of components, by training local experts, in the installation and operation of test laboratories and by measuring systems on site. Our main areas of work at present are:

- setting up an accredited test laboratory in Indonesia (together with TÜV Rheinland)
- establishing a test laboratory in Senegal
- qualifying a Moroccan institution for quality assurance of the local electrification programme
- advising the Argentinian federal government and the electricity utilities involved in rural electrification



Fig. 1: Training technicians in the Moroccan test laboratory.



Fig. 2: Accredited test laboratory at LSDE in Serpong, Indonesia.

- concept for setting up quality assurance infrastructure for PV systems in Nepal.

Apart from training experts in our test laboratories, our offer includes the planning, procurement, delivery and installation of customised test facilities for PV modules, charge controllers, batteries, inverters and electric appliances such as lights, television sets or refrigerators. We have developed a complete set of measurement equipment, test procedures and test protocols, which we adapt individually according to the experience and direction of the partner institutions.

Quality of Solar Home Systems (SHS) - Examples from Senegal, Bolivia and Nepal

Photovoltaics in Solar Home Systems (SHS) can provide electricity for light and radio or television reception in rural areas, remote from public electricity grids, throughout the world. Fraunhofer ISE accompanies electrification programmes with quality assurance, training, industrial advice and marketing concepts.

J. Kuhmann, O. Parodi, **K. Preiser**, P. Schweizer-Ries, D. U. Sauer, O. Thieke

The pre-condition for successful dissemination and long-term use of solar systems in rural areas is the integrated introduction of technically high-quality products. Local production of the components is decisive. National quality standards must be adapted to the specific usage conditions and the technical competence of local companies. The corresponding work should not be limited to purely technical solutions, but must take account of the problems which are encountered in reality in operating SHS.

Thus, in 1996 Fraunhofer ISE prepared a list of the currently applicable standards for SHS and their components in Senegal, within a project for the Gesellschaft für Technische Zusammenarbeit (GTZ - Society for Technical Cooperation). During a three-day seminar in Dakar, we discussed the resulting quality criteria and test procedures with the Senegalese authorities responsible.



Fig. 1: Production of the "Toyo Solar" battery in the Bolivian BATEBOL company.

As part of PROPER, a German-Bolivian project on rural electrification, the Institute supports several Bolivian companies in establishing local production. They manufacture charge controllers, electronic ballasts for fluorescent lamps and batteries for Bolivian projects on Solar Home Systems for remote households. Tests at Fraunhofer ISE still revealed flaws in the locally manufactured products: fluorescent lamps stopped operating after only a few switching cycles, some electronic ballasts did not operate correctly even when new. We identified faulty components, poor workmanship and inadequate quality controls as causes and discussed possibilities for improvement with the companies involved in Bolivia. A further example is the "solar battery" of the BATEBOL company. Together with BATEBOL, we established measures for a higher storage capacity, better forming and drying of the grid plates and additional quality controls, which BATEBOL has adopted in production.

What are the expectations of SHS users, how do they use the new technology and what influence does it have on their lives? That was the focus of our work in Nepal, in which we investigated more than 100 SHS in two different mountain regions and tested Nepalese SHS components in our laboratory. There is a large potential for improving the quality of both the systems in the mountains and the products in the capital city, Kathmandu. Despite this, the SHS users are very satisfied with their systems, most of which they built themselves. The demand for new installations is increasing constantly. However, the mountain population does not usually know where it can buy components and how these can be combined to a functional system. The self-built systems are often not optimally installed and maintained. For instance, modules are shaded, there are no charge controllers, incandescent lamps instead of energy-saving fluorescent lamps are used and batteries are refilled with acid instead of with distilled water. On the basis of this experience, we have prepared concepts for the dissemination and long-term use of SHS (marketing, installation, maintenance, guarantee, etc.) in the Solu-Khumbu region in Nepal. At present, we are discussing their advantages and disadvantages with Nepalese companies.

Full-page illustration: Solar Home Systems in the Himalayas: Since 1993, lights, radio and television have operated on solar electricity in Pulimarang, Nepal (see article p. 60).

Highly Efficient Charge Controller with DC/DC Converter for Photovoltaic and Fuel Cell Modules with a Small Number of Cells

In order to obtain conventional supply voltages, many individual cells are connected in series in PV modules and fuel cell stacks. This has disadvantages: a considerable labour component, mismatches and greater sensitivity of PV modules to partial shading. Highly efficient DC/DC converters significantly reduce the number of cells which must be connected in series.

Ludwin Anton, Tim Meyer, **Heribert Schmidt**, Frank Schneider*

Solar cells and fuel cells supply voltages between about 0.4 and 2 V, depending on the materials and technology used. Typical supply voltages, however, are 12 or 24 V, which are obtained by connecting many cells in series. Solar cells are mass-produced with dimensions of app. 10 x 10 cm^2 to 15 x 15 cm^2 and rated power of app. 1.5 to 3.5 W_p. In a standard module with 36 cells to operate a 12 V system, the resulting module power is 50 to 125 W_p.

For lower module power values, cells are cut into pieces, e.g. with a laser, and connected in series. Figure 1 shows this type of module, consisting of 36 quarter-cells, with a power of about 10 W_p. This module construction is labour-intensive and results in loss of power due to the differing properties of the quarter-cells and greater sensitivity to partial shading.

Together with an industrial partner, we developed a novel module concept in which the required module power is obtained by series connection of only a few, undivided cells. The necessary supply voltage is provided by a DC/DC converter with an integrated charge controller function. Figure 2 shows this type of module with four undivided cells as an example. It also supplies power of 10 W_p with an operating point voltage of 1.8 V and a current of app. 5.5 A. This modular concept allows a wide spectrum of module power to be supplied by varying the number and type of cells. This advantage is particularly beneficial if the subsequent converter also operates over wide voltage, current and power ranges and has a very high efficiency value.

A charge controller with a DC/DC converter was developed according to these principles in cooperation with the Solarwatt company from Dresden within the research programme, "Photovoltaics for Appliances and Small Systems", funded by the German Federal Ministry of Economics and Technology BMWi.

A module power of 10 to app. 40 W_p and an input voltage range of 2 to 10 V with a maximum current of 5 A were specified. The output voltage can be selected for 12 or 24 V lead-acid battery systems. Temperature compensation for the end-of-charge voltage is integrated, as is time-delayed load disconnection and potential-free output of a preliminary warning signal if deep discharge occurs. Figure 3 shows the circuit board of the prototype.

An optimised circuit concept guarantees a high efficiency value for all combinations of input parameters, even under partial load.

After intensive testing, the Solarwatt company will manufacture the device in series.

*SOLARWATT Solar-Systeme GmbH, Dresden

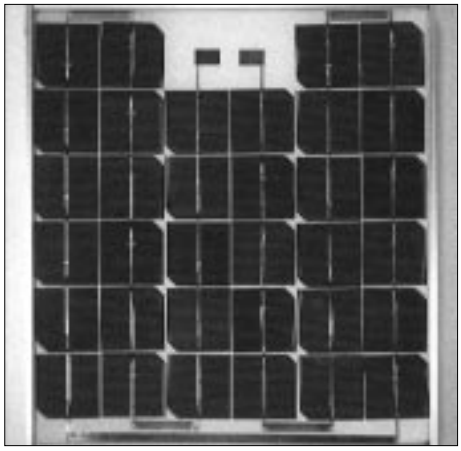


Fig. 1: 10 W_p module with 36 quarter-cells connected in series.

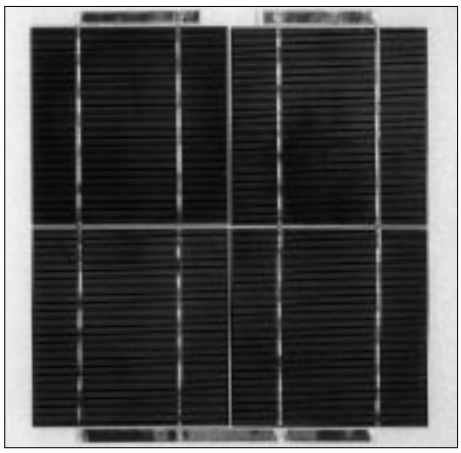


Fig. 2: 10 W_p module with 4 complete cells connected in series.

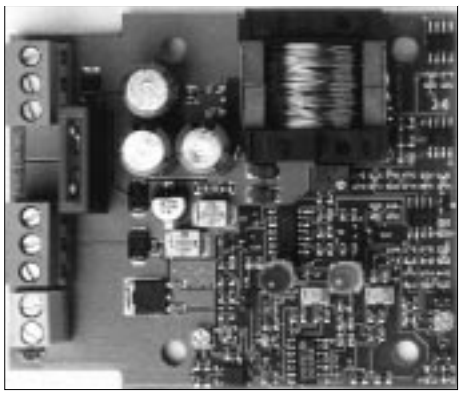


Fig. 3: Prototype of the charge controller with a DC/DC converter. V_{in} = 2 - 10 V, I_{in} = 5 A, P_{max} = 40 W.

Measurement of Inverters in European Photovoltaic Systems

Project staff: G.Bopp, J.Kuhmann, J.Ketterer, H.Schmidt

Measurements carried out throughout Europe on inverters integrated in photovoltaic systems in the Concerted Action project indicated a high standard of quality.

Along with France, Spain, Greece, Italy and Holland, ISE is participating in the European "Concerted Action" project, which collects and makes use of information on photovoltaic systems. Questions in this project, for example, include: How well does the system function? Does the system operator feel confident with the system? What experience has been learned for application to future PV systems?

Serving as a connecting link between the PV array, the batteries and the AC consumer, the inverter plays a central role in the system and is often the largest single cause of energy losses. Because of the varied experience gained in laboratory measurements on inverters, it was possible for ISE, within a short timespan, to develop a new measurement technique for inverters on location. Measurements on location are difficult due to the restrictive conditions of the surroundings. In these tests, the characteristics of each inverter, for example, open circuit losses, efficiencies, dynamic behaviour and curves of the input and output components (voltage, current), were tested using an 8-channel harmonic and power analyser (fig. 54).





Fig. 53: Inverter for a stand-alone system, TOP CLASS 3000 (3kVA)
Fig. 54: (far left): Harmonic and power analyser „EWS 94"

Measurements on nine different inverters in different power ranges (2.5kVA - 60kVA, single and three-phase, stand-alone and grid-connected) in France, Greece, Holland and Germany have shown two main aspects: The technology is improving constantly and there is some need for improvement in several characteristics, for example, the partial load efficiency. Examples of good and bad partial load efficiencies are shown in fig. 55. For a slowly rising efficiency characteristic, an appreciable fraction of the current produced by the solar array is lost i.e., the economic efficiency of the PV system falls sharply.

For the most part, grid-connected inverters with thyristors have good partial load behaviour; they cause, however, especially in weak grids, appreciable grid reactions and are vulnerable for fuse blow-outs during disturbances in the public grid.

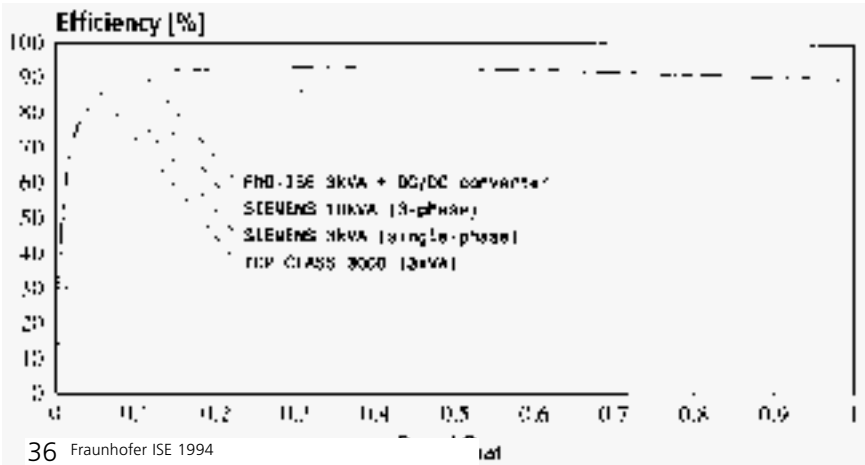


Fig. 55: Efficiency characteristic of several inverters tested in this work.



Electromagnetic Compatibility of Photovoltaic Systems and Components

We help to ensure the electromagnetic compatibility (EMC) of new equipment under development and already installed systems, with our stationary and mobile EMC measurement technology and our experience in standardisation.

Georg Bopp, Thomas Erge, Steffen Schattner



Fig. 1: View into the EMC measurement chamber at Fraunhofer ISE.

The increasing density and interference potential of electric components, devices and systems means that their electromagnetic compatibility is becoming an increasingly important quality aspect. "Electromagnetic compatibility" of a device means that it does not disturb its electromagnetic environment by more than a moderate amount. On the other hand, it should be sufficiently resistant to disturbing influences in its own environment. The limiting values are defined in extensive standardisation literature.

Of course, photovoltaic systems are not immune to electromagnetic incompatibility. On the contrary: Television and radio reception was disturbed by some of the photovoltaic systems in the 1000 Roofs Programme. Interference with telephone and radio systems was also reported. In Solar Home Systems, it is often impossible to receive medium-wave radio transmissions after lights with their electronic ballasts have been switched on.

In larger PV systems, it is primarily the extensive DC side with its - unfortunately - excellent antenna properties which is responsible for the disturbances. Awareness of this aspect of EMC has only developed gradually among the manufacturers of potential sources of interference, such as inverters and charge controllers. The boundary conditions are not conducive either: The technical standards are still being written. Nevertheless, the law obliges the manufacturer to ensure EMC. This is unsettling for the manufacturers. Often they do not know how to proceed or which standard is applicable.

We are able to help here: Within an EU research project together with the Dutch partner, KEMA and the Swiss partner, HTA Burgdorf, we have prepared an up-to-date overview of standards, measurement configurations and recommendations, and applicable limiting values. Specifically for the DC side, a line impedance stabilisation network (LISN) was defined for simple and reproducible measurements and limiting values were recommended for the international standardisation process. This limit must be observed whenever a new device is developed. Up to 500 kHz, the DC limit of EN 55014-1 is applicable; at higher frequencies it is about halfway between the AC and DC limits of this standard.

We advise our clients with respect to limits, accompany developments with measurements in our shielded EMC measurement chamber or certify products within the Fraunhofer EMC consortium. Improvement of a product to meet the standards at an early stage in its development is generally much less expensive than subsequent measures. However, we are also able to help with our mobile EMC measurement technology if disturbance from PV systems arises on site (this also applies to protective measures against lightning or overvoltage). For Solar Home Systems, we have developed a reliable and inexpensive recommended procedure for measurements in the laboratory and on site.



Module Calibration - An Efficient Method for Quality Assurance

The booming photovoltaic market in Germany has increased the demand for module measurements enormously. An increasing number of wholesalers and installation companies is commissioning us to characterise random samples taken from large module orders in our flashlamp laboratory or outdoors, to check the specifications given by the manufacturers. The technical facilities for both types of measurement services are ideal in our new building. Our staff has also grown, so that we can provide optimal service to our clients.



Fig. 1: Measurement of a photovoltaic roofing tile unit.

Klaus Kiefer, Frank Neuberger, Wilhelm Warta, Jürgen Weber

Our expertise

Thanks to our long years of practical experience in PV measurement technology, we can offer our clients:

- reliable measurement results, which are guaranteed by regular participation in round-robin tests with other internationally recognised measurement laboratories
- compliance with international standards in all calibration steps and in the use of reference elements and measurement facilities
- continuous further development of the measurement procedures in accordance with research activities at Fraunhofer ISE
- rapid, non-bureaucratic processing
- strict confidentiality guaranteed
- regular maintenance and testing of our measurement equipment
- intensive and competent advice on individual measurement requirements

Our services

We characterise PV modules of all constructions up to dimensions of 2 x 2 m^2:

- module measurement with a pulsed solar simulator (flashlamp)
- outdoor module measurements
- determination of the NOCT temperature and power output
- measurement of the angular and temperature dependence of the module parameters

Our measurement facilities

ISE CalLab is equipped with high-quality measurement facilities to meet demanding measurement challenges.

- class A steady-state solar simulator (AM 1.5; AM 0)
- simulator with three light sources
- concentrating solar simulator (up to 1 200 suns)
- pulsed solar simulator (AM 1.5)
- outdoor measurement stand
- filter monochromator (300 nm to 1 400 nm)
- grating monochromator (300 nm to 1 800 nm)
- various spectroradiometers

Internet

For more detailed information, simply consult our Internet site at http://www.callab.de. From there, you can also easily place measurement orders by e-mail.



Photovoltaics for Appliances and Small Systems

The aim of our activities is to develop marketable appliances and small systems with photovoltaic power supplies. We specialise in supporting small and medium-sized enterprises to exploit the potential offered by photovoltaics for diverse, innovative products.

Sergej Aingorn, Jochen Benz, Jérôme Kuhmann, **Werner Roth**, Wolfgang Schulz, Andreas Steinhüser, Gerrit Volck

Photovoltaically powered products are the main focus of the programme on "Photovoltaics for Appliances and Small Systems", which is funded by the German Federal Ministry of Economics and Technology BMWi. Further, the development of components and measurement instruments for use in small photovoltaic systems can also be supported. Small and medium-sized enterprises, as defined by EU subsidy guidelines, are eligible to apply. They can choose between two different forms of support:

Co-operation between an enterprise and Fraunhofer ISE

This form is directed mainly toward enterprises which do not have much experience with photovoltaics, do not have suitable laboratory equipment or wish to draw on the experience of Fraunhofer ISE. We support the enterprise within the framework of a co-operation agreement. The spectrum ranges from consultancy to joint development of marketable products. We concentrate on system design, photovoltaic electricity generation, energy conditioning, energy storage, reduction of consumption and energy management.

Development work carried by the enterprise

Here, the enterprise is completely responsible for making the development. It receives a grant of maximally 35 % of the costs which are eligible for the subsidy.

This year, we co-operated with industrial partners to develop photovoltaically powered products for lighting technology, water purification, public transport, measurement technology and information technology.

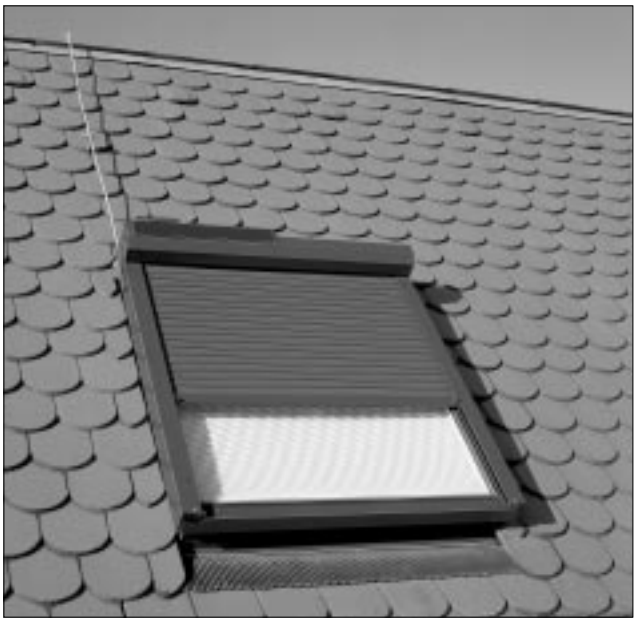


Fig. 1: Photovoltaically powered roller blinds: Maintenance-free and convenient to operate with remote control (photo: WAREMA).

Photovoltaics for Appliances and Small Systems

An increasing number of appliances and small systems are operated independently of a central power supply. Often a grid connection is not feasible or too expensive. A photovoltaic power supply is a good option. We support small and medium-sized enterprises in exploiting the wide range of innovative potential offered by photovoltaics for new products

Sergej Aingorn, Jochen Benz, Rudi Kaiser, Frank Kreuz, Norbert Pfanner, **Werner Roth**, Dirk Uwe Sauer, Heribert Schmidt, Andreas Steinhüser

Traffic direction system

Particularly along the federal motorways, traffic direction systems with prismatic displays are being installed in increasing numbers. The displays consist of rotatable, prismatic segments, and are usually connected to the 230 V grid. Together with the company, via traffic controlling gmbh, we have developed a stand-alone system with cable-free data transfer and intelligent sensors. The system has a photovoltaic power supply and consists of a 3-facetted prismatic display in an aluminium frame, which can display three traffic signs. In addition to the mechanical drive system for the prisms, the frame houses the circuit board for the controls, a GSM radio modem and the charge controller. A planar GSM antenna is mounted on the frame. An infrared sensor to measure the road surface temperature, an anemometer or a radar detector for speed control could also be added to the system.



Fig. 1: Photovoltaically powered prismatic display: Rapidly installed, requiring little maintenance and simple to control via the mobile telephone network. (Source: via traffic controlling gmbh).

The solar-powered prismatic display is primarily intended for traffic direction in built-up areas (fig. 1). A timer, remote controls or sensor-based control can be used to select the different traffic signs.

Solar powered outdoor lights

In addition to street and footpath lighting, accent lighting is often needed at locations away from the public electricity grid (fig. 2). We have co-operated with Moonlight GmbH to develop, construct and test a stand-alone photovoltaic power supply system for spherical and hemispherical lamps.

We investigated various types of lighting technology to achieve energy-efficient and homogeneous illumination of the spheres. For spherical lamps of up to 35 cm diameter, a light was developed with super-bright LED's in combination with a constant current source. Larger lamps are equipped with compact fluorescent lights. In lamps with several light sources, operation is optimised by a control unit which automatically switches the lights on and off according to the state of charge.

Southern countries, with high ambient temperatures, represent one of the main regions where photovoltaically powered accent lighting is applied. For these applications, we have equipped the switch box (fig. 3) with a heat exchanger to cool the battery. The heat exchanger is powered by the



Fig. 2: Beach lighting with spherical lamps. (Source: Moonlight GmbH).



excess energy available when the solar radiation intensity is high. This measure extends the battery lifetime significantly.

Maintenance-free, stand-alone power supply

Stand-alone power supplies are used for e.g. transponders, sensors and telematics systems, and allow maintenance-free and reliable operation over very long periods of time.
If the power demand is very low, primary batteries can also be used for operation over several years.
However, as soon as the consumption is higher and off-grid operation is required, a stand-alone power supply with a photovoltaic generator is the first choice. As the energy supply and demand do not generally coincide, a rechargeable battery is also needed. It should have a high efficiency value, be very reliable and have a long lifetime.

Often, these specifications can not be met by one type of storage technology alone. This applies particularly if the solar irradiation is subject to strong seasonal variation. Then energy must be stored in summer and be available for use in winter. In addition, the power supply must be very reliable. For instance, if the rechargeable batteries are discharged completely, a warning signal is sent to the central control station, and further reliable operation is guaranteed with an emergency reserve.

Our concept is very flexible and allows diverse battery types, loads and photovoltaic generators to be operated in parallel (fig. 4).

As all components are connected to a common DC bus, its voltage can fluctuate within a wide range. A capacitor stabilises the voltage of the DC bus, so that a continuous current supply to the load is guaranteed even during switching processes. The load is supplied with constant voltage via a DC/DC converter. Almost any number of rechargeable batteries can be connected to the DC bus. A primary battery is connected via a diode to the DC bus and only supplies energy when the voltage on the DC bus is lower than the voltage of the primary battery. The overall concept ensures that this can happen only when all of the rechargeable batteries are completely discharged. In this concept, the primary battery has the lowest voltage level of all the storage units. Its lifetime should be equal to at least twice the time between two maintenance checks, and its self-discharge should be minimal. We aim for 10 years of operation without maintenance for the complete system.
A patent claim for the concept has been filed. The German Federal Ministry of Economics and Technology BMWi funded this work within its programme on "Photovoltaics for appliances and small systems".



Fig. 3: Switch box to house the energy storage unit and control electronics. The heat exchanger to cool the batteries can be seen on the roof. It is powered with excess electricity from the photovoltaic generator.

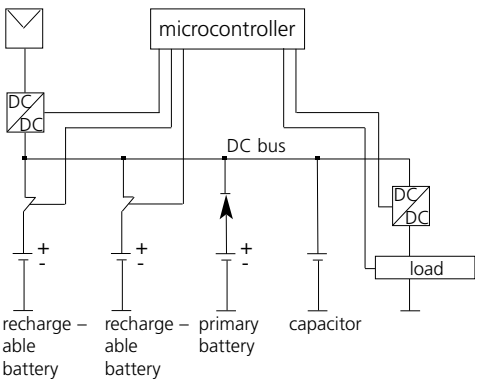


Fig. 4: Block circuit diagram of a system for seasonal storage of energy, with a lifetime goal of ten years.

Photovoltaically Powered Information Systems

Information and telecommunications systems are often installed and operated far away from the public electricity grid. A grid connection is often not possible or very expensive. A photovoltaic power supply is then an economically attractive option.

Ludwin Anton, Werner Roth, **Wolfgang Schulz**

We cooperate with industrial companies to develop innovative products with photovoltaic power supplies. These include information systems.

We will present two examples in this article: a "Multi-functional emergency call and information system" and a "Photovoltaically powered information display for public transport stops".

The multi-functional emergency call and information system was developed for use on highways and major roads, but also within cities, at bus stops and bathing pools. It is an emergency call and information terminal: On the one hand, it is a radio emergency call system for the user, on the other hand, information such as traffic and weather data can be collected at the system location and transferred to central data acquisition units. An energy management system provides the operating voltages for the emergency phone and the various sensors. It can disconnect individual loads of secondary priority if the energy supply is insufficient. The aim of the energy management is to guarantee reliable operation of the emergency phone.

The photovoltaically powered information display for public transport stops was developed to improve the quality of information for public transport passengers, above all in rural areas. Conventional servicing of the locations is associated with high costs for power and data cables. The new, photovoltaically powered information displays receive information on deviations from the timetable by radio. The expected departure times or delays can then be read on-line by the waiting passengers from LCD displays which withstand outdoor conditions. Newly developed LED light-guiding plates provide energy-saving illumination of the displays when it is dark. In combination with a miniature movement sensor, the illumination can be turned off during overcast periods. An energy management system (fig. 1) provides the energy for these functions. It switches the individual loads off and on according to their priority within the complete system. In addition, it generates the operating voltages needed for the LCD display and processes the associated information and data in a multiplexor procedure.

The work is supported by the German Federal Ministry for Economics and Technology BMWi within the research project on "Photovoltaics for Appliances and Small Systems".

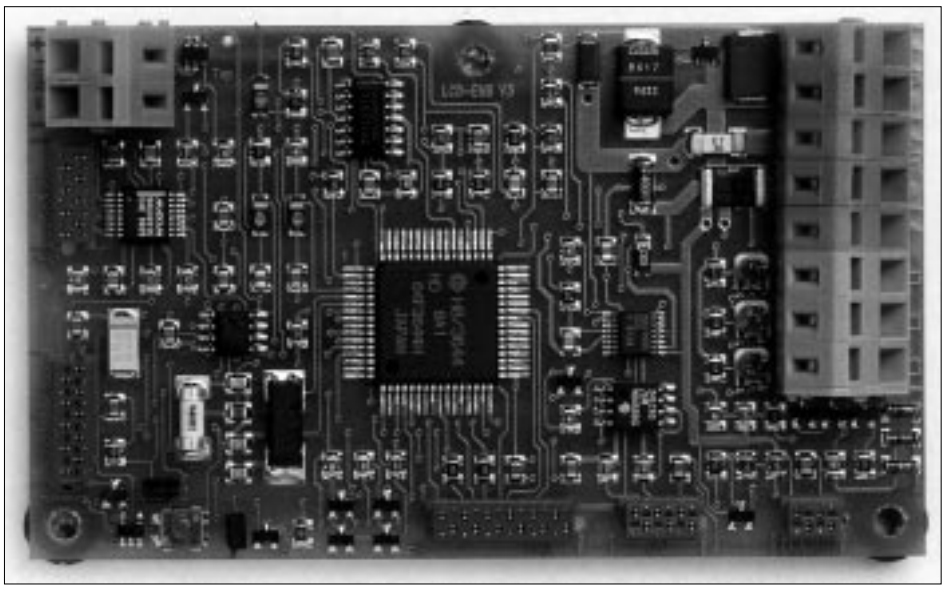


Fig. 1: Energy management system for a photovoltaically powered LCD information display.



Batteries - Core Components for all Stand-Alone Power Supplies

The operating conditions for batteries in stand-alone power supplies differ appreciably from classical applications. We characterise various storage technologies in the laboratory and in field tests. We develop charging strategies, charging electronics and algorithms to give reliable indications of the state of charge and the ageing condition of the batteries.

Oliver Bohlen, Edward Gareis, Rudi Kaiser, Jérôme Kuhmann, **Dirk Uwe Sauer**, Heribert Schmidt, Birgit Thoben, Gerrit Volck

Battery storage units are needed in all stand-alone power supplies with a continuous energy demand. This applies for mobile devices (e.g. mobile phones, laptops), stationary technical devices (e.g. timetable displays, signal systems) and for household power supplies (e.g. Solar Home Systems, mountain lodges, village power supplies). Profound knowledge of the storage unit is an essential basis for successful system development. The primary aim of our activities is to optimise the complete system and minimise the costs of the storage system.

We investigate small batteries for applications in appliances. Currently we are studying lithium ion batteries and rechargeable alkali manganese (RAM) cells. We concentrate on typical stresses found in stand-alone power supplies, such as very low currents during charging and discharging, high and low temperatures, infrequent complete charging and long periods in the partly discharged state. We test the batteries both under controlled conditions in the laboratory and also under real operating conditions outdoors with detailed measurements.

Today, larger systems still use lead-acid batteries almost exclusively. In recent years, increased use has been made of closed, maintenance-free batteries. However, appropriate charging strategies are still being sought for use in photovoltaic power supply systems, which adequately meet the demands of both the batteries and the system with its users. Together with battery manufacturers, we investigate charging strategies in comparative field tests and analyse the results with respect to lifetime and system performance. The knowledge gained is applied in improvements to charge controllers or device and system controls.

In order to gain more insight into the ageing behaviour of batteries, we also develop detailed models. Suggestions to improve operation and the battery design are based on these. In future, we aim to determine the lifetime of lead-acid batteries after only a short testing period, using a combination of electrochemical tests and modelling. Simplified models are also used in our simulation programs for system design.

Modern power electronics and the general avoidance of current-smoothing elements like capacitors and inductors mean that batteries today are subjected to an increasing proportion of AC current components. The effects are still largely unknown or are the subject of considerable controversy. Within a project funded by the European Union, we are investigating the effect of pulsed currents on the electric performance and the ageing of lead-acid batteries. We were able to demonstrate that the real charge transfer in the batteries is appreciably higher than is measured with standard measurement technology. The reason is that charging and discharging currents occur simultaneously. The resulting battery current can reverse its polarity with a frequency between 1 and 300 Hz, which can result in a charge transfer which is up to 20 % higher than assumed, depending on the system.

In order to supply high system voltages, many individual lead-acid batteries must be connected in series. The weakest link (e.g. a damaged cell) determines the performance of the entire system. In order to guarantee maximal system performance even when individual cells are defective, we develop charge-equalising systems (CHargeEQualizer). They are now equipped with an integrated battery monitoring system with monitoring and analysis of the individual cells.

To enable integration of the storage unit into devices and systems, the system management requires continuous information on its state. This includes not only the state of charge but also the instantaneous capacity, an indicator for the ageing status of the battery. To this purpose, we are developing algorithms which do not require sophisticated measurement technology and which can be easily integrated into the microcontrollers of charge controllers, device controls and energy management systems.

Field Test of Operation Management Strategies for Valve-Regulated Lead-Acid Batteries

On commission to the Exide German Group, we constructed systems for comparative tests of charging and operation management strategies for valve-regulated, no-maintenance lead-acid batteries in real PV systems. The batteries will be intensively measured and examined over 3.5 years. The aim is to maximise the battery lifetime by suitable operation management.

Dirk Uwe Sauer, Georg Bopp, Klaus Göbel, Hans-Georg Puls*, Michael Rosa

* free-lance

Vented lead-acid batteries with liquid electrolytes have been the most important storage componants for electricity in PV systems to date. Compared to these, valve-regulated lead-acid batteries have the advantage that the elctrolyte is fixed in position in glass mats or as a gel. This prevents sulphuric acid from escaping through leaks, and gases which form can recombine internally. This reduces the water losses to the extent that valve-regulated batteries requre effectively no maintenance during their lifetime. In addition, leakage of explosive and corrosive gases in considerably reduced.

Despite their advantages, valve-regulated batteries have not often been used in PV systems. Untested and unsuitable charging and operation management strategies have often shortened the lifetime. Experience gained so far with batteries containing liquid electrolytes connot be transferred. In commission to and cooperation with the Exide German Group, wich includes the Hagen Batterie AG, Accumulatorenwerke Sonnenschein and Deta Batterien companies among others, we are testing operation management strategies in real PV systems. The work is supported by the German Federal Ministry of Education, Science, Research and Technology BMBF. We are investigating a total of 26 batterie systems in four different types of system. Five different battery models and technologies (gel, glass mats, tubular and grid plates) with capacities between 34 and 300 Ah at system voltages between 12 and 162 V are involved. The current, voltage and temperature of altogether 238 battery cells or blocks are continuosly monitored and analysed in the test. Ten battery systems are integrated into hybrid systems, in which a diesel or gas generator is available in addition to the PV generator, whereas the other 16 systems are purely PV/battery systems, e.g. for lighting purposes or parking voucher vending machines.

We have developed system concepts and software, which allow us to test batteries under the same boundary conditions (energy supply form the PV generator and enery demand by the system user) in real systems. The German Mountaneering Club DAV and other users have placed existing PV systems at our disposal. The differing operation management strategies - variable end-of-charge voltage thresholds, different maximal depths of discharge, use of the auxiliary generator - are implemented by computers. They record the measured data and control the various components. All of the systems are monitored centrally from the institute.

After construction of the systems, the batteries will be measured for 3.5 years and subjected to comprehensive capacity tests egvery six months. We expect to gain thorough knowledge of the effects of the various operation management strategies from the evaluation of the measured data, the results of the capacity tests and physico-chemical analyses of the cells during and at the end of the test phase. In addition, reliable comparisons can be made of batteries with gel or glass mats as a matrix, and tubular or grid plates.



Fig. 1 : Four 12 V battery systems in the Talhof system near Rottweil, each consisting of 6 individal cells of the type OPzV (tubular plate, valve-regulated) with 300 Ah each. Measurement technology can be seen in the background, and to the right, two batteries as back-up power supplies for the main computer.

We took 24 of the 26 battery systems into operation in three different PV systems up to the middle of May, 1998. By the end of October, all systems had been completed and the first round of capacity tests carried out. The systematic investigations are already providing initial indications to the benefit of future system operators.



Development of Test Procedures for Storage Batteries in Stand-Alone Power Supply Systems

There are no suitable test procedures available today which can reliably determine the lifetime of batteries in stand-alone power supplies. We are developing procedures to characterise batteries according to their application conditions. In addition, we are working on procedures for accelerated ageing tests.

Dirk Uwe Sauer, Pascal Fischer, Rudi Kaiser, Hans-Georg Puls

Batteries are responsible for a large share of the costs in stand-alone power supplies. The lifetime of the batteries depends very much on two factors:

- choice of the optimal battery type or appropriate battery technology
- setting of the operating conditions

However, there are not yet any test procedures which can reliably determine the lifetime of batteries in stand-alone power supplies within a short testing time. This is partly because the operating conditions are influenced decisively by the application, the location and the system configuration.

In addition, many ageing effects occur in parallel in batteries, which are not all intensified by the same factor in accelerated ageing tests. Therefore, the results cannot be rescaled to normal battery operating conditions. Even under accelerating conditions, ageing tests on good batteries last for at least one year; if real operating conditions are applied, 5 to 8 years must pass before reliable results become available.

We are working in two projects on procedures which allow the lifetime behaviour of batteries in stand-alone power supplies to be characterised.

In the "BENCHMARKING" project (which started in January 2002), we are co-operating with leading institutes from Europe, USA and Australia to characterise and classify the operating conditions of batteries. Data from real systems are analysed and used to determine the stress profiles on the batteries. A typical testing cycle will be developed for each class of operating conditions. This can be used to conduct non-accelerated ageing tests, which give a reliable lifetime value for the tested battery in the corresponding class of operating conditions. Further, the aim is to develop accelerated testing cycles, which also reproduce the operating conditions as closely as possible.

The development in the "ACTUS" project goes a step further. There, a novel procedure for accelerated ageing tests of lead-acid batteries is being developed together with industrial companies and partners specialised in the electrochemistry of batteries. It consists of a combination of electrochemical tests and lifetime simulation of the ageing behaviour of lead-acid batteries in a system. Specific electrochemical or physical tests are to be developed for each of the different ageing mechanisms, which will be used to characterise the test object's vulnerability to ageing. None of the tests should last longer than three months. After three months, characteristic values for the various ageing effects will be available. We use these data to determine the parameters for a detailed, physico-chemical ageing model of the battery. We can use this to simulate the lifetime under different operating conditions. Determination of the characteristic values once will thus allow quick calculation of the lifetime which can be expected. At the same time, the results will be verified within the project with non-accelerated ageing tests.

Both projects are funded by the EU.

Fraunhofer ISE is also participating in the "INVESTIRE" network, which is led by CEA-GENEC, Aix-en-Provence and funded by the EU. 35 partners will document the current status of all types of storage technology for stand-alone power supplies, and evaluate their potential for development. We are responsible for determining the operating conditions in different application classes.



Fig. 1: We have a total of more than 50 battery testing circuits for short-term and long-term electrical characterisation, with current ranges between 20 mA and 300 A and voltages between 1 V and 500 V. Three water baths and two temperature-controlled cabinets are available to keep the battery temperature at the required value.

Understanding Batteries Better to Reduce Costs

Lead-acid batteries are the only economically feasible storage units for electricity in larger, grid-independent PV systems. In order to reduce the high running costs caused by the short lifetime of batteries, the institute is systematically investigating the stresses they experience and developing life-extending operating strategies.

Georg Bopp, Dirk Uwe Sauer, Hans-Georg Puls

Almost all stand-alone photovoltaic systems require energy storage. Despite many alternative suggestions, only nickel-cadmium and lead-acid batteries have been widely used. Nickel-cadmium batteries have longer lifetimes but lower efficiency values and are significantly more expensive. Thus only lead-acid batteries come into question for the foreseeable future, but their lifetimes are still unsatisfactory. We hope to lengthen the lifetime considerably by systematically investigating and understanding the internal processes, and then deriving optimal operation management and system configuration.

In a joint project running several years with the Centre for Solar Energy and Hydrogen Research ZSW, the Institute for Solar Energy Supply Technology ISET and the company, Wirtschaft und Infrastruktur & Co Planungs-KG WIP, we are starting by comprehensively evaluating around 30 battery systems in PV installations. We have divided the operating conditions into four classes according to the solar fraction and the capacity of the storage unit. In table 1, the significance of various battery properties in the different classes is indicated. This allows appropriate batteries to be selected.

Based on aging models for lead-acid batteries and detailed models of all other components, we have developed a tool with which photovoltaic hybrid systems can be optimally designed and operated. The aim is to optimise the system lifetime such that costs are minimised, taking all boundary conditions into account. We simulate the system in time steps over the assumed lifetime - usually 20 years - and include the following costs: initial investment, capital costs, maintenance, cost of replacement parts (mainly for the battery). Apart from these, other boundary conditions are the location, the price of diesel and user specifications such as supply reliability or the regenerative energy fraction.

Operation management has a vital influence on the battery lifetime and the demand for auxiliary energy. Thus, the operation management parameters were optimised simultaneously with the component dimensions. Subsequently, the operation management structure can be simply implemented with a microprocessor in modern charge controllers or energy management systems.

	class 1	class 2	class 3	class 4
solar fraction	100 %	70 - 90 %	about 50 %	below 50 %
storage capacity	> 10 days	3 - 5 days	1 - 3 days	about 1 day
cycling stability	less important (> 300)	←	→	important (> 1200)
cycling in deep discharge conditions	important	←		less important
low self discharge	important	←		less important
measures against acid stratification	important	very important		less important
resistance to corrosion	important	←		of limit. importance

Table 1: Selection criteria for lead-acid batteries according to the typical planning parameters for PV systems, solar fraction and storage capacity.

Aging Performance of Lead-Acid Batteries in Photovoltaic Systems

Lead-acid batteries are the only economically viable storage units for photovoltaic systems at present. However, the relatively short battery lifetimes cause high operating costs. The aim of the work is to develop operating strategies to lengthen battery lifetimes.

G. Bopp, D.U. Sauer

An electricity storage unit is needed in almost all stand-alone photovoltaic applications remote from the grid. It compensates for the natural day/night cycle of the sun, meets short-term peak power demands and tides over short periods of overcast weather. Lead-acid batteries are used almost exclusively because of their high efficiency values and good charging performance. At present, batteries have lifetimes of only three to eight years in photovoltaic systems. As a result, the battery costs over the system lifetime amount to about one third of the total and are thus considerably higher than the cost of the solar generator. As lead-acid batteries can achieve longer lifetimes or higher energy transfers under other conditions, operating strategies are being developed for photovoltaic systems, which improve their performance under the specific conditions experienced there.

A joint project between ZSW in Ulm, ISET in Kassel, WIP in Munich and Fraunhofer ISE is thus being funded by BMBF to analyse the stresses which batteries are subjected to in photovoltaic systems. The aim is to analyse data measured over several years from about 30 photovoltaic battery systems. Efficiency values, frequency distributions for current, voltage and temperature, changes over time and correlations between important quantities will then be determined. The change with time of the battery's state of charge, a decisive criterion of judgement, is calculated from the recorded data according to a sophisticated procedure. As an example, fig. 1 shows that the battery of a photovoltaically powered bus shelter (without an auxiliary generator) was not fully charged for several months in winter.

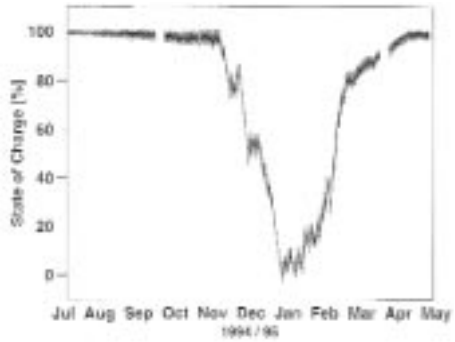


Fig. 1: Calculated battery state of charge for a bus shelter lighting system in 1994/95.

Beyond the scope of this project, Fraunhofer ISE is also working on quantitative models for battery aging. An intermediate step to this goal is computer-supported modelling of the acid density distribution in lead-acid batteries. The numerous partial cycles with low currents and infrequent full charging cause stratification of the acid density, which reduces the effective capacity and leads to locally different aging processes (fig. 2).

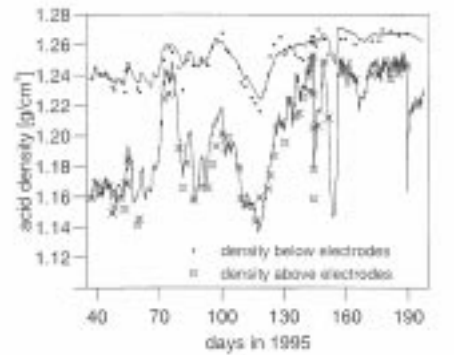


Fig. 2: Temporal change of the acid density above and below the battery electrodes at the self-sufficient solar house in Freiburg. The solid lines were obtained by simulation of the acid distribution, the points are the results of manual measurements.

Full-page illustration: Computer simulation of a specific case of solar irradiation.

Longer Lifetimes and Better Use of Batteries with the CHarge EQualizer - Successful Tests and Further Developments

A long lifetime and high reliability of the battery are the pre-conditions for successful application of photovoltaics in applications isolated from the grid. The new "CHarge EQualizer" system makes a decisive contribution toward achieving this.

L. Anton, **H. Schmidt**, C. Siedle

In many applications, primary or secondary batteries provide the required operating energy, beginning with torches, continuing with portable computers and telephones, and including electric vehicles, stand-alone photovoltaic systems, non-interruptible power supplies or large systems belonging to electric utilities as a grid back-up. In almost all of these applications, a series connection of battery cells provides the required operating voltage. In larger photovoltaic systems or for electric vehicles, several hundred 2 V lead-acid batteries can be involved. Even when brand-new, manufacturing tolerances for the cells lead to differing properties, which then diverge further during operation due to temperature gradients or aging processes. These individual characteristics result in major differences in the state of charge and finally overcharging, deep discharging or inverse charging of single cells, accompanied by further damage. This chain reaction is one of the main causes for premature breakdown of many multiple-cell battery banks.

The "CHarge EQualizer" (CHEQ) developed at Fraunhofer ISE counteracts this mechanism by active charge equalisation between the series-connected cells. For every application, from small appliances to large systems, the Institute has developed tailor-made procedures for automatic charge equalisation, implemented these in practicable circuits and tested them in laboratory and field experiments.

An extremely good result was obtained in a comparison of batteries for electric vehicles, with and without CHarge EQualizers. In cooperation with the battery industry (Advanced Lead Acid Battery Consortium ALABC) and a neutral testing institute, three sets of batteries, each of sixteen 6 V/160 Ah gel batteries, were subjected to a charge cycling test. The reference battery consisted of 16 selected, well-matched blocks with a thermal management system to ensure an almost constant temperature. In the two test batteries, 9 of the 16 blocks were manipulated - 3 stood in a water bath at 30 °C, 3 had not been cycled and thus had a significantly smaller capacity, and 3 further blocks were discharged by 10 % before the beginning of the test. One of these modified batteries was equipped with a T-CHEQ system, the other with a commercially available charging unit with individual cell monitoring and top-up charging of individual cells. The optimised

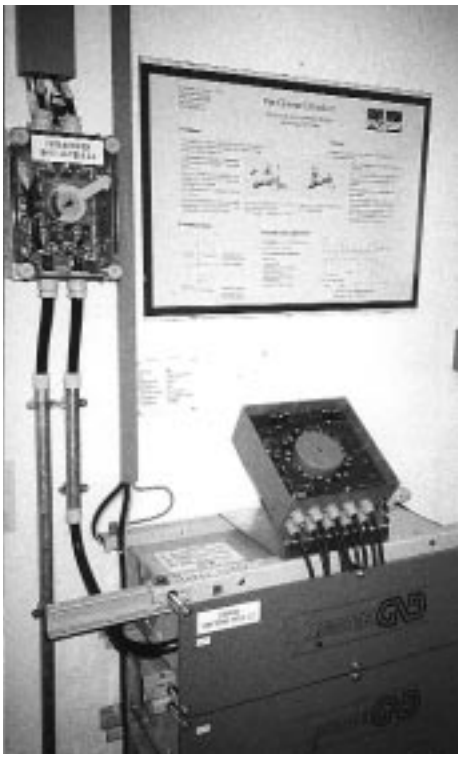


Fig. 1: 48 V Absolyte battery with T-CHEQ at the Swabian electric utility, EVS, in Laichingen.

reference battery survived about 550 full cycles, the battery with the conventional unit about 350, but the battery combined with the T-CHEQ reached more than 600 full cycles. Not only was a higher cycling lifetime achieved than for the reference battery, but the battery efficiency value was 8 % higher on average with the T-CHEQ.

Testing Lithium Ion Rechargeable Batteries for PV Devices of the Future

Up to now, mainly lead or NiCd batteries have been used as power supplies for photovoltaically powered devices. Compared to them, lithium ion (Li ion), rechargeable batteries are characterised by a number of positive properties: no memory effects, high energy density, relatively simple recognition of the fully charged state even with variable charging currents. We tested Li ion rechargeable batteries under realistic operating conditions as preparation for their integration into industrial solar products.

Hans-Joachim Höfer,
Jérôme Kuhmann, Werner Roth,
Andreas Steinhüser, Gerrit Volck

The electric properties of the energy storage unit have a strong influence on the performance of a photovoltaic system. Thus it is imperative to accurately characterise the components of a new storage technology before it is introduced. We investigate Li ion rechargeable batteries in detail under the boundary conditions which occur in a photovoltaically powered device, such as small and fluctuating charging currents and a wide range of ambient temperatures. As well as fundamental investigations, we also test the lifetime and durability of Li ion cells in long-term tests with charging/discharging cycles, at various currents, in the laboratory and outdoors.

Some of the investigation results for Li ion cells with $LiCoO_2$ as the positive and carbon as the negative electrode respectively include:

- The energy which can be extracted from the cell with very low discharging currents (I_{100}, I_{200}) is practically constant over a wide temperature range (-10 °C to 60 °C) (fig. 1).

- The Li ion cell can be successfully charged also at low temperatures (-10 °C) and with very low charging currents (I_{20}, I_{100}), (fig. 2).

- The self-discharging rate is only about 2 - 3 % per month at room temperature.

- The energy efficiency value for charging and discharging currents of I_5 is very high, exceeding 95 %.

We set up an outdoor test stand for long-term testing of Li ion cells under the conditions which prevail in a PV device. The Li ion cells are charged photovoltaically and then discharged with a defined load profile.

We are able to offer comprehensive services to industrial partners using the test equipment we have set up within the research project on "Photovoltaics for Appliances and Small Systems", which is funded by the German Federal Ministry for Economics and Technology BMWi.

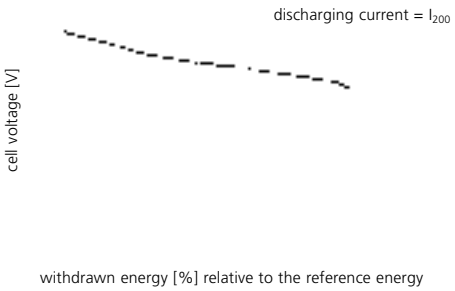


Fig. 1: Discharging characteristic curve for a Li ion cell at a discharging current of I_{200} and a range of ambient temperatures.

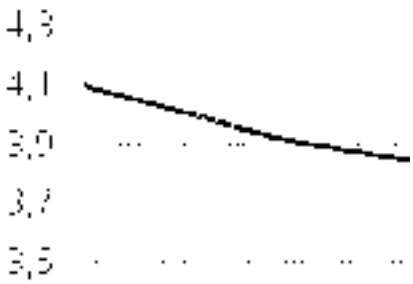


Fig. 2: Charging/discharging characteristic curves of a Li ion cell for different current values.



Fig. 3: Outdoor test stand for long-term investigations of Li ion cells. It is equipped with eight test channels, each with a Li ion cell, charging electronics, an ohmic resistance and a solar module.

IIntelligent Electricity Distribution Grids for the Energy Market of the Future - EDISON

A consortium of 16 industrial SME and research partners, EDISON, will develop and demonstrate flexible electricity distribution concepts which are competitive in a liberalised energy market. It will integrate innovative decentralised generation, storage, information and communications systems into a complete concept.

Gerhard Weissmüller*,
Heribert Schmidt,
Thomas Stephanblome**,
Dusan Povh***

Today's electricity supply systems are based on the structure illustrated in fig. 1, with large, central power stations that supply consumers via a dense distribution grid.

This structure will suffer increasingly in the liberalised markets, as it is not flexible enough in the choice of primary energy sources to allow energy flows and energy costs to be optimised. In addition, obtaining authorisation for large technological power plants or grid extensions will become more and more complicated.

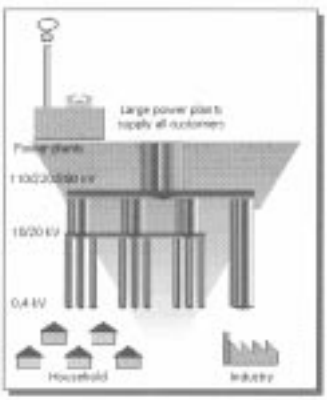


Fig. 1: Present structure of electricity distribution grids.

Furthermore, this type of capital-intensive structure could hardly be implemented for comprehensive electrification in developing countries. The EDISON strategic project aims to develop novel grid structures which enable both the optimisation of existing grids in industrialised countries and ecologically acceptable electrification in threshold countries.

The approach is a transition to the structure presented in fig. 2.

It facilitates the integration of decentralised components:

- generators such as photovoltaic and wind energy systems, (fuel cell) heat/electricity cogeneration
- local energy storage units to optimise energy flows
- power quality equipment to actively improve the voltage quality by reducing voltage breakdowns, compensation of harmonic distortions and spanning short interruptions.

Medium-voltage DC links are also applied to exchange power between the distribution grids. These decentralised grid components operate



Fig. 2: Future, decentralised grid structure with superimposed communications network.

essentially autonomously, but are connected via a communication network with each other and the central control units of the utilities. Apart from tasks immediately associated with power supply, such as reading meters or controlling loads, the communications network also opens new markets such as security monitoring, telephone communication or Internet access - of particular interest for municipal utilities.

Fraunhofer ISE initiated the establishment of a consortium with 16 partners from industry, small and medium-sized enterprises SME, and research institutes, and cooperates with the Karlsruhe Utility, EUS GmbH from Gelsenkirchen and Siemens AG from Erlangen in leading the EDISON strategic project, which started in the middle of 1999 with funding from the German Federal Ministry of Economics and Technology BMWi.

The consortium will define the basic principles for this type of grid and test them in three different grid regions belonging to the Karlsruhe Utility and the Baden-Württemberg utility, EnBW.

In the project work, Fraunhofer ISE will concentrate on the topics of energy converters and storage elements, and implementing and monitoring demonstration systems. This includes not only modelling energy converters and storage units but also developing reformers for fuel cell heat/electricity cogeneration and preparing strategies to determine the state of charge and lifetime extension of batteries.

* Stadtwerke Karlsruhe GmbH (Karlsruhe utility)
** EUS GmbH, Gelsenkirchen
*** SIEMENS AG, Erlangen



Towards the Electricity Grid of the Future

We are working in a consortium of 17 partners from industry and research on a decentralised grid structure with an integrated communication system. The aim is a high-quality power supply and the greatest possible flexibility for technical and economic options.

Heribert Schmidt, Thomas Erge, Angelika Heinzel, Dirk Uwe Sauer, Dieter Schlegel

The Karlsruhe Stadtwerke (city utility), Fraunhofer ISE in Freiburg, EUS GmbH in Gelsenkirchen and Siemens AG in Erlangen are managing the consortium, which calls itself "EDISON". The consortium has set itself two tasks to be completed by 2003: adaptation of the energy distribution grids to the liberalised electricity market, and preparation for modern technology such as renewable energy.

EDISON combines energy distribution with information processing and is developing decentralised components for the new grid structure. Examples of components include:

- power quality equipment, which e.g. compensates for voltage breakdowns
- local electricity storage units, which ensure a homogeneous energy flow
- decentralised electricity generators such as photovoltaic and wind energy systems, or heat/electricity cogeneration plants with fuel cells.

Together with decentralised energy management systems, these components open up new options for demand-relevant control of energy flows in extended electricity distribution networks.

This applies, for instance, when cogeneration plants based on fuel cells are introduced, which can both meet peak electric loads and supply heating energy. The energy utility can use cogeneration plants particularly efficiently if their electric output can be controlled according to the demand. The decentralised communication structure allows access to the electricity generator at any time. This means that expensive grid extensions can be avoided.

Another application is to meet a temporarily raised demand for electricity in an environmentally friendly way in grid segments which were not designed for this load, e.g. the power supply for building sites or folk festivals. Mobile storage batteries with an energy management system can eliminate the need for large diesel aggregates or costly expansion of grid structures.

Thus, the introduction of additional decentralised generators and storage units may not be measured economically, purely on the basis of the electricity production costs or the savings in electricity trading which result from reducing the peak load. The essential savings for the utility arise from the avoided investments for extending the grid with power lines and transformers.

We are primarily responsible for two scientific sub-projects for EDISON:

- sub-project 2, "Energy storage and conversion units"
- sub-project 7, "Monitoring and analysis of results"

In sub-project 2, we co-operated with partners to initially document the state of the art concerning energy storage and conversion units. We are testing components in the laboratory to investigate their operating characteristics and to determine technical parameters. Based on this, we develop new hardware and software to optimise their operation.

In sub-project 7, we are comparing the currently used, decentralised energy conversion and storage units by analysing the system data on energy and power. The data are transferred on-line from the decentralised operation management system to the process management system and then stored in our data bank. In addition, we install measurement sensors and data loggers in selected systems or components.

The EDISON project is supported by the German Federal Ministry of Economics and Technology BMWi.

Solar Air Conditioning for the Meeting Room of the Chamber of Commerce in Freiburg

Solar desiccant cooling is an environmentally friendly technology for air conditioning, which operates without any cooling agents that attack the ozone layer or contribute to the greenhouse effect. Because of the low driving temperatures, it is very well suited to combination with thermal solar collectors and waste heat e.g. from heat/electricity co-generation plants.

Sascha Backes, Christian Bichler, **Carsten Hindenburg**, Volker Kallwellis*, Mario Motta

Last year, the first German air-conditioning system to be powered exclusively by solar energy in summer was installed and commissioned in Freiburg. It air-conditions the large meeting room and a cafeteria on the penthouse floor of the Chamber of Commerce for the Southern Upper Rhine region. The desiccant cooling system has a rated volume current of 10 200 m^3 per hour in connection with a 100 m^2 solar collector array for air heating.

We designed the system and dimensioned it using the simulation models we have developed. Together with a large controls technology company, we commissioned the system at the end of June, 2001. It has passed the first summer with flying colours. Even when the outdoor temperatures exceeded 35 °C, the indoor temperatures remained pleasant. The project (fig. 1) has two special features:

- The solar air collectors form the only heat source to regenerate the sorption agent.
- There is no thermal energy storage unit.

This meant that we could simplify the system technology and significantly reduce the investment costs for the solar systems technology. As a result, the proportion for the solar air collectors and their installation was less than 10 % of the total investment costs.

In addition to air conditioning in summer, the system also makes a noticeable contribution toward the space heating in the transitional and winter months. Figure 2 shows the 100 m^2 solar air collector field on the roof of the Chamber of Commerce.

Within the scientific support programme, apart from critically checking the concept in practice, efforts will be concentrated on optimising the system controls and operation management, and analysing the energy balance. The real measured system and room air parameters will be used to validate and improve the existing simulation models. This means that desiccant cooling systems can be planned and dimensioned still more reliably in future.

Leadership of and participation in the European project, "ASODECO: Advanced Solar Driven Desiccant Cooling Systems for Central European and Mediterranean Climates", with eight partners from four countries, ensures that comparison with other solar driven cooling systems can be made.

We are grateful to the European Union, the State of Baden-Württemberg, and the companies GWE Gesellschaft für wirtschaftliche Energieversorgung mbH & Co. KG in Freiburg, Dieter Bühler Ingenieurbüro GmbH in Bahlingen and Grammer KG Solar-Luft-Technik in Amberg for financially supporting this innovative system.

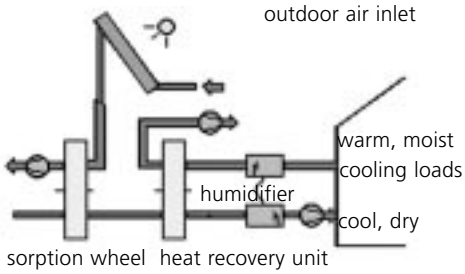


Fig. 1: Schematic diagram of the system.



Fig. 2: Solar air collector system on the roof of the Chamber of Commerce for the southern Upper Rhine region.



Fig. 3: View of the air-conditioned cafeteria.

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg



Solar Air Conditioning

For the last 6 years, we have intensively investigated ways of air-conditioning buildings with solar energy. Our R&D activities range from the development of new cooling processes based on adsorption technology, through scientific support of pilot and demonstration systems, to consultancy for planners and architects.

Andreas Baumeister,
Hans-Martin Henning,
Carsten Hindenburg, Mario Motta,
Tomas Núñez, Katja Scheuble,
Tim Selke*, Edo Wiemken

Use of solar energy to air-condition buildings in summer is an attractive option because the seasonal profiles for demand and solar supply are well synchronised. Practical experience shows, however, that the systems must be carefully designed and constructed, if the intended energy savings compared to conventional systems are to be achieved. We are working on processes which apply thermal solar energy for cooling and/or air dehumidification (fig. 1).

In addition to basic research (materials research, see article on p. 32; research on heat and mass transport in adsorption systems), scientific support of pilot and demonstration projects is an important aspect of our investigations. Table 1 gives a summary of the most important projects. With these projects and numerous studies on new systems, we have gained a broad knowledge base on the processes, possibilities and limits of solar air-conditioning.

We have investigated system concepts for different climatic regions (e.g. Bangkok in Thailand, Isfahan in Iran and Palermo in Italy) and can adapt them to other local requirements. Meanwhile, we have developed physical-mathematical models for all the essential components of solar air-conditioning systems and validated simulation tools.

Our experience will be documented in a handbook on solar air conditioning, which is currently being prepared within Task 25 on "Solar Assisted Air Conditioning of Buildings", in the Solar Heating & Cooling Programme of the International Energy Agency IEA, under the leadership of Fraunhofer ISE.

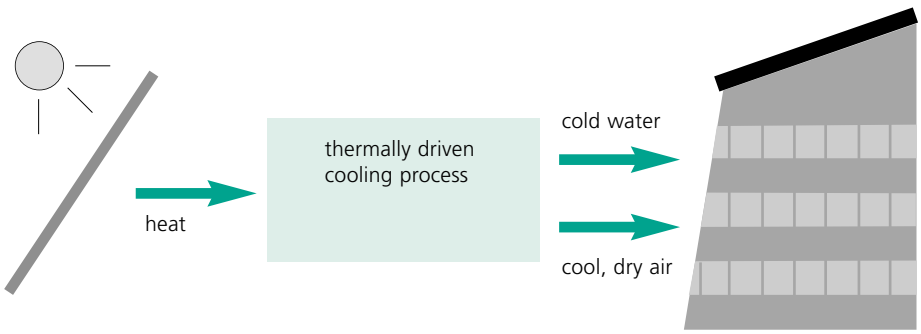


Fig. 1: General system diagram for solar air conditioning of buildings.

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Project	Funded by	Tasks undertaken by Fraunhofer ISE	Start of operation
Desiccant Cooling System for the Technology Centre in Riesa	State of Saxony	project management; conception and planning of the complete system; support during installation and commissioning; supporting measurements	1997
Solar Desiccant Cooling System for an Office in Portugal	EU Thermie	project management; conception and planning of the complete system; supporting simulation; design of the monitoring system and the system controls	1999
Solar Cooling with an Adsorption Chiller	BMWi	consultancy during the planning phase; scientific support of operation; detailed measurement data acquisition and analysis, supporting simulation; development of optimised control concepts	1999
Design and Installation of a Solar Driven Desiccant Cooling Demonstration System	EU-INCO-COPERNICUS	conception and planning of a desiccant cooling system for solar air conditioning of a lecture theatre at the university in Eriwan, Armenia; development of the controls; support during commissioning; monitoring and supporting simulation	2001
Advanced Solar Desiccant Cooling Systems for Central European and Mediterranean Climates (see article on p. 51)	EU	project management; conception and planning of a solar desiccant cooling system for a meeting room at the Chamber of Commerce in Freiburg; support during commissioning; supporting measurements and analysis; development of the controls	2001

Table 1: Summary of the most important projects on solar air conditioning involving Fraunhofer ISE.



Test Facility for Solar Desiccant Cooling Systems

Solar desiccant cooling systems (SDCS) present an environmentally friendly alternative to conventional air-conditioning systems. Integration of thermal solar systems is particularly promising due to the low operating temperature of SDCS. We have been working intensively on this topic for several years and set up a new test facility last year.

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The main components of the test facility are:

- sorption-assisted air-conditioning system with a nominal volume current of 4000 m^3/h. A system of these dimensions can provide air conditioning for seminar rooms with 40 - 80 persons.
- 20 m^2 solar collectors with a liquid heat transfer medium,
  20 m^2 solar air collectors,
  2 m^3 buffer storage tank

With the test facility (fig. 1), we can configure sophisticated hydraulic circuits and thus investigate 4 to 5 very different SDCS simultaneously. As specified by our clients, we investigate both the performance of the complete system and that of individual components under real, non-stationary solar operating conditions. Optional conditioning of the ambient air makes us practically independent of the prevailing ambient conditions.

We offer the following services to our clients:

- development and analysis of energy-optimised control strategies for SDCS
- measurement and further development of sorption wheels; close co-operation with the thermo-analytical laboratory of Fraunhofer ISE means that we can develop and directly test new sorption materials
- measurement and further development of thermal solar collectors specifically for air-conditioning applications
- development of cost-optimised combinations of thermal solar energy with SDCS
- system investigations and comparison with accompanying system simulations
- development of controllers for solar and non-solar SAAC systems
- development of customised software solutions to simulate SDCS



Fig. 1: Test facility. The following companies provided financial support for its construction: Solvis Solarsysteme GmbH, GREENoneTEC Solarindustrie GmbH, Sonnenkraft GmbH Deutschland, Grammer KG Solar-Luft-Technik, Landis&Staefa GmbH Region München, Viega, robatherm GmbH.

Thermal Solar Collectors for Building Air-Conditioning

Solar heat can cool - e.g. via sorption processes with water as the working medium. Building air-conditioning in summer is a particularly attractive application of thermal solar collectors in buildings: The greatest demand occurs at the same time as the highest solar radiation levels. The technology has proved itself in pilot plants for commercial applications. Widespread introduction is particularly interesting for the Mediterranean region initially.

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Carsten Hindenburg,
Frank Luginsland, Tim Selke,
Gregor Trunk

Various technologies are available for solar thermal air-conditioning in buildings: desiccant cooling technology, absorption cooling technology and adsorption cooling technology. Fraunhofer ISE offers consultation, concept studies and scientific evaluation on all these technologies.

Examples of projects include:

- design of the system and control technology of a solar desiccant cooling system for the Technology-Orientated Entrepreneurial Centre in Riesa-Groflenhain (funded by the State of Saxony)

- concept and scientific evaluation of the slar desiccant cooling system for the ATECNIC office building in Sintra, Portugal (funded within the THERMIE programme of the EU) (fig. 1)

- scientific support of solar cooling with adsorption cooling technology for a laboratory building at the University Hospital in Freiburg (funded by the German Federal Ministry of Economics and Technology BMWi)

- conception of the solar desiccant cooling plant for a lecture theatre at the American University of Armenia in Eriwan, Armenia (funding from the INCO-COPERNICUS programme of the EU)

Within its Solar Heating and Cooling Programme, the International Energy Agency IEA started a new Task 25, "Solar-Assisted Air Conditioning of Buildings", to promote the market introduction of this technology on an international scale. Fraunhofer ISE is leading this project, in which nine countries are participating at present. Within five years, the working group aims to further develop existing and new technologies for solar-assisted air conditioning and modern planning tools. Further information can be found in the brochure (fig. 2), which can be obtained from Fraunhofer ISE. This activity, which is supported by the German Federal Ministry of Economics and Technology BMWi, allows solar thermal and air-conditioning companies to benefit directly from the scientific dialogue around the world.



Fig. 1: Solar thermally powered, solar desiccant cooling plant for an office building in Sintra, Portugal.



Fig. 2: Cover page of the flyer about Task 25 in the Solar Heating and Cooling Programme of the International Energy Agency IEA.



"Club zur ländlichen Elektrifizierung C.L.E" - Association of German Industrial Companies to Develop the Market for Rural Electrification

A questionnaire sent out by Fraunhofer ISE in April 2000 revealed that the German photovoltaic and systems technology branch had considerable need for a common strategy to penetrate the market for rural electrification. As a result, 16 companies founded the "Club zur ländlichen Elektrifizierung C.L.E." in September 2000. Fraunhofer ISE is the coordinator for C.L.E., which already has a membership of 20.

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Silke Drescher*, Klaus Preiser

Already 20 German companies, ranging from module manufacturers through system developers to installation and finance companies, have combined to co-operate in the "Club zur ländlichen Elektrifizierung C.L.E.". Their common goal is to penetrate the markets for rural electrification. C.L.E. is aiming to achieve a sustainable PV economy in Germany. To this end, C.L.E. intends to establish permanent structures in developing countries which will enable stable export markets for German solar companies. C.L.E. is a broadly based export initiative, in which German photovoltaic businesses will improve the boundary conditions for photovoltaic export and implement decentralised power supply concepts.

C.L.E. brings together the complete spectrum of expertise on rural electrification represented by the member companies. This allows comprehensive and coherent presentation in the strategically significant solar markets - down to marketing of the internationally recognised quality seal, "Made in Germany".

In addition, by acting as a consortium, C.L.E. enables its members, mostly small and medium-sized enterprises, to compete successfully on the global market.

At the same time, C.L.E. sees itself as a representative of the photovoltaic branch to German bodies responsible for promoting export, in matters concerning rural electrification. These are primarily the German Federal Ministries of Economic Co-operation and Development BMZ, and of Economics and Technology BMWi, the Society for Technical Co-operation GTZ, the Kreditanstalt für Wiederaufbau KfW and the Export Council for Renewable Energy, which is currently being established. Essential goals include improved information flow, adequate inclusion of German companies in projects in developing countries and support for German companies in penetrating markets e.g. by close connection with developmental aid projects or credit guarantee mechanisms.

An important aspect is that the export promotion instruments be appropriately adapted to the markets for rural electrification. 10 000 Solar Home Systems, each worth 1 000 euros, require a different form of support to a hydroelectric power station with a value of 10 million euros. Creation of relevant boundary conditions in the target countries (taxes, customs, etc.) is also a topic of discussion.

C.L.E. has already had important meetings with the ministries and will co-operate with them closely to further improve the boundary conditions for exporting technology for rural electrification.

C.L.E. also aims to bring together companies with different products, so that they can combine in submitting quotes for system or electrification solutions. In joint actions, market information will be obtained and studies on particular markets or countries prepared, partners in the target countries identified through trading companies or participation in trade fairs, and quality standards introduced, which are based on those already existing on the market.

Close co-operation with the associations representing the German solar industry is fully expected by C.L.E. The legal form for C.L.E. was finalised at the end of 2001.

Further members are welcome. Information about the goals of C.L.E. and its members can be found in the Internet under www.cle-export.de.

*free-lance