# PV VILLAGE POWER SUPPLY SYSTEMS IN CHINA
# - RESULTS FROM A TECHNICAL MONITORING CAMPAIGN

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ABSTRACT: China has the largest program world wide for village electrification with remote systems based on renewable energies. 721 PV hybrid systems have been built by the end of 2005 in the western provinces under the Chinese National Township Program. All components came from Chinese manufacturers. Another 124 villages were electrified with co-financing of the German KfW using in part components from German suppliers. The German GTZ supports the Chinese efforts through training programs for the trainers of system operators and through technical monitoring of selected villages. Twelve village systems in Qinghai were equipped with data logging equipment which registers 10 min average values of currents and voltages, radiation and temperature values. First evaluations show that the households which are connected to the new distribution systems are supplied regularly with electricity. Energy consumption patterns are determined more from the supply than from the demand side, a 24 hour by 24 hour supply is not yet achieved. Technical measures may improve the utilisation of the energy which is "theoretically" available. The overall experience however is surprisingly good, the systems which are in the monitoring program work reliably.
Keywords: rural electrification, hybrid systems, village supply, China, monitoring

## 1 INTRODUCTION

China has undertaken major efforts during the last two decades to establish modern infrastructure for transport, communication and electricity supply throughout its large country. In this context, the government of the P. R. of China has decided to launch the "Brightness Program" [1] with the aim to provide electricity services to the 30 million people who not yet have access to electricity supply. The autonomous regions of the P. R. of China Tibet, Xinjiang and Inner Mongolia as well as some of the western provinces, e. g. Qinghai, Sichuan and Gansu, have extensive areas which are sparsely populated and which are, in the perspective of the national electricity grid, very remote. It is planned to supply a larger part of the people living in these remote areas with electricity produced locally from renewable sources.

The Brightness Program started with a pilot phase (1999 – 2002) which brought electric light from single photovoltaic solar home systems and from photovoltaic/ battery systems of village supply size to 50,000 people in Inner Mongolia, Gansu and Tibet. The second phase (2002 – 2005) was called the "Township Program". It supplied electricity to 400,000 people with a focus on Tibet, Xinjiang and Qinghai. All together 15,500 photovoltaic solar home systems were installed and 721 townships (villages with seat of local authority) were equipped with village supply systems mainly based on photovoltaic electricity.

The "Brightness Program" is a program of the Chinese Government, Chinese money – 200 Million Euro for the current "Township Program" – were spent, almost all the equipment – PV-modules, batteries, inverters etc. – are Chinese design and from Chinese producers. China has, at the moment, by far the largest village electrification program with stand alone renewable energy systems. And the next phases of the electrification program are under preparation: A "village program", synchronised with the 11. Five year plan (2006 – 2010) with an installation of 250 MW of PV capacity to supply 2 Mio households, and a second phase shall then follow (2011 – 2015) supplying another 2 Mio households.

**Table I:** The Chinese National Township Program, Status of realisation by end of the year 2005.

| Province | Number PV/ (wind) hybrid systems | Installed power PV ($kW_p$) | Ø – Installed power ($kW_p$) | Number of installed SHS | Installed power ($kW_p$) |
|---|---|---|---|---|---|
| Hunan | 1 | 20 | 20 | 0 | 0 |
| Shaanxi | 9 | 100 | 11.1 | 0 | 0 |
| Qinghai | 112 | 2715 | 24.2 | 6800 | 136 |
| Gansu | 23 | 995 | 43.2 | 0 | 0 |
| Xinjiang | 159 | 2378 | 14.9 | 7133 | 356 |
| I.Mongolei | 42 | 752 | 17.9 | 1525 | 610 |
| Sichuan | 46 | 1817 | 39.5 | 0 | 0 |
| Tibet | 329 | 6763 | 20.6 | 0 | 0 |
| **Summe** | **721** | **15540** | **21.5** | **15458** | **1102** |


**Figure 1:** Sites of the photovoltaic village systems in the "Township Program"

The national Chinese program is supported and complemented by activities from other sides. The German Kreditanstalt für Wiederaufbau (KfW) for example co-financed up to now 124 PV/battery village supply systems and more will follow [2, 3]. The German Gesellschaft für Technische Zusammenarbeit (GTZ) on behalf of the German Government has been providing technical assistance to the Township Program in the provinces of Yunnan, Qinghai, Gansu and Tibet [4, 5, 6].

By means of supporting existing institutions, both, on the national and on the provincial level, as well as by enforcing market mechanisms and by promoting private initiatives, it is intended to establish favourable framework conditions and to implement appropriate strategies for the large-scale dissemination and sustainability of renewable energy systems. In this context the Fraunhofer-Institut für Solare Energiesysteme ISE and the Zentrum für Sonnenenergie- und Wasserstoff-Forschung (ZSW) have been commissioned by GTZ to develop training and monitoring programs, which shall ensure sustainable operation and functionality for the 112 PV systems in Qinghai province.

## 2 A VISIT TO THE COUNTRYSIDE

Suohourima, to give one example, is a township in Qinghai which was electrified in the year 2003. Situated 900 km from the capital of the province, 70 km from the next electricity line at 4.000 meters above sea level, Suohourima has between 300 and 400 households, the office of the local authority, a clinic and a school.

In a first step 200 households and the official buildings were connected to the village electricity grid. The new electricity supply replaces the old Diesel-generator set which is no longer in operation.

The equipment is installed in a newly built "power house" which also gives home to one of the two operators who were trained to take care of the system. Power is typically supplied to the households from sunset until 01:00 hours in the morning. For special events or if the operator has the impression that the battery is really full, the hours of supply may be longer.

**Figure 2:** Suohourima township in November 2005

**Figure 3:** Photovoltaic generator, 40 kW, in front of the new power house in Suohourima

**Figure 4:** Battery bank in the power house, AGM type, lead acid

**Figure 5:** Cabinets with inverters and AC-distribution. Typical chest freezer to the right

**Table II:** Suohourima township, components of the electricity supply system

| | |
|---|---|
| PV-generator | 40 kW, 26 parallel strings with 18 modules, 85 W per module, manufacturer Qinghai Gaofai, cells from Astropower, US |
| Charge controller | 13 channels, µC-controlled, sub arrays are switched off at the end of charge voltage of the battery, manufacturer Hefei Sunlight Power |
| Battery | Sealed (AGM) lead acid battery, cells 2 V/1300 Ah, 3 parallel strings with 110 cells, 858 kWh, manufacturer Enersys Huada Solar |
| Inverters | PWM with transformer and µC-control, 220 VDC/220 VAC, 1 inverter with 16 kW, 1 inverter with 24 kW, manufacturer Hefei Sunlight Power |
| AC Distribution | 2 isolated and not grounded single phase grids supply different parts of the township. The single households have electronic energy meters |
| Households | All electrified households have electric light (fluorescent lamps (9W) or incandescent lamps (40W)), 90 % of the households have colour TV + satellite receiver + DVD player, and chest freezer to store meat, more and more households have electric heating blankets and pillows, some have washing machines (for external hot water supply) |

**Figure 6:** Street scene in Suohourima. Washing machine to the left

**Figure 7:** View into a living room of a school teacher: radio, TV with DVD, personal computer

**Figure 8:** Street scene in Suohourima. Small solar home systems on the sidewalk to charge individual batteries

## 3 TECHNICAL MONITORING: WHY AND HOW?

There is more than one good reason to evaluate the working of the realised village supply systems in a quantitative way:

- The electrification authority, the utility which eventually operates the supply systems and the institutions which give the money will want to know if the final users, the families living in remote country villages, get adequate modern energy services. They will want to know numbers on household consumption, on the development of consumption patterns with time, they want real numbers on the technical lifetime of system components, they want numbers on operation and maintenance costs in order to design sustainable financing and billing schemes.
- The system integrators want to know, if their systems are working continuously, they want to know where there is room for optimisation of layout and coordination of system components to avoid unnecessary losses, to increase energy utilisation and finally to reduce the specific investment costs.
- And last but not least, electricity supply systems at village level are still a new technology where many questions are open, many problems still have to be solved and large potentials for optimisation are still open for exploitation. Monitoring of technical system performance will facilitate and accelerate that process.

On behalf of GTZ Fraunhofer-ISE and ZSW developed a program for the technical monitoring of the 112 village supply systems which were realised under the Chinese National Township Program in the Province of Qinghai. The Qinghai Provincial New Energy Research Institute (QNERI), local partner of GTZ in Qinghai, involved from the beginning in the installation of the PV village supply systems, has installed the monitoring equipment and collects the data. Data evaluation is performed in a common effort between Fraunhofer-ISE, ZSW and QNERI.

After an on-site inspection of 7 newly electrified townships in 2004, a four level concept for technical monitoring was proposed which meanwhile has been implemented.

- Written reports: The local operator in each of the 112 villages fills out daily data sheets with generation and consumption values.
- "Small" data logging
- "Full size" data logging
- Mobile measurement equipment for verification and maintenance of the PV systems and calibration of the data loggers.

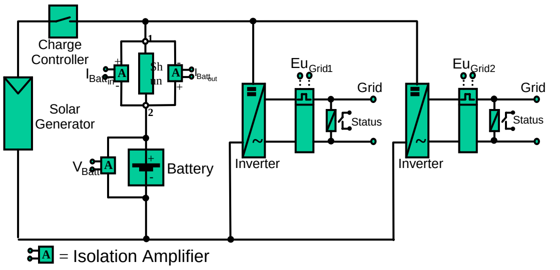


**Figure 9:** The "small" data logging system, block diagram of measuring points

Seven townships have been equipped with the "small" data logging system, which measures 8 signals, including solar radiation.

As data logger a WEB'log Pro from the German company Meteocontrol is used. Manual data transfer is possible with a memory card. Where a telephone connection exists, an automatic email data transfer to a data server takes place each night. With a password the data at the server are available for evaluation and processing.

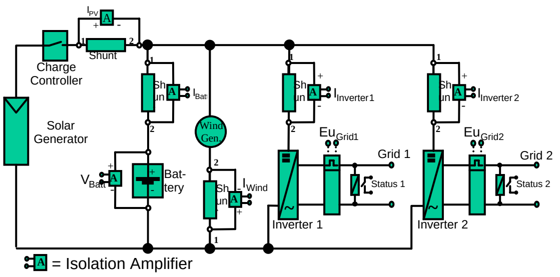


**Figure 10:** The "full size" data logging system, block diagram of measuring pints

Five townships have been equipped with the "full size" data logging system, which measures 15 signals, including solar radiation, ambient temperature, PV-module temperature and battery temperature.

As data logger an IDL 100 from the Austrian company Gantner is used. Manual data transfer is possible with a memory card. Where a telephone connection exists, a manual data transfer from QNERI via analogue telephone modem is possible.

In March 2005 staff from QNERI was trained to program and install the data loggers. During this training course one "small" data logging system was installed at the township Duosong and one "full size" data logging system at the township Kesheng. QNERI then installed the remaining data loggers. In November 2005 a training course was held on data evaluation.

## 4 FIRST RESULTS AND CONCLUSIONS

At the time of writing this paper (August of 2006) most of the Data Acquisition Systems are installed, the data are gathered and first evaluations are made. The process of data transfer from the very remote measuring sites is, it must be admitted, not as fast and continuous as some of us may have hoped.

However, the results from the village systems where quantitative evaluation can already be made are surprisingly good.

- The systems supply electric energy to the households day after day without larger breaks. This means that all components, after the usual failures during first installation were fixed, are working very much to satisfaction. Figure 10 gives one example for an evaluation of one of the DC/AC-inverters (system Suohourima, nominal power 24 kW, December 2005).

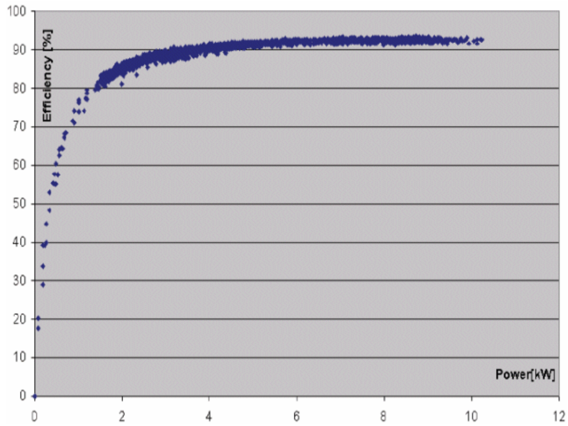


**Figure 11:** Efficiency of the 24 kW inverter at Suohourima, 10 min averages from one month

- Average electricity consumptions in the single households differ considerably from village to village. The values are between one third and one kilo-Watt hour per household and day. The difference is not due to different consumption patterns but rather to differences on the supply side (see below). The measured household consumption agrees with the values which are known from other countries like Indonesia or Brazil [7] for low-income rural households supplied from larger grids. Turning this argument around: electricity saving efforts are not clearly seen in the measured consumption values.
- Energy is not yet regularly delivered for 24 hours per day. The operator switches the village distribution line on and off according to his or her perception of the energy situation. Typically the inverters will be connected to the village distribution at sunset, will then be switched off around midnight at low battery voltage, at sunrise at better battery situation or not at all, if the batteries are full (figures 12 and 13). At the evening peak, the load is two to three times higher than during the day (if electricity is available). Part of the evening load comes from electric heating blankets which are used in the beds and which are very welcome in the cold Himalayan climate. This special use of electric power however was certainly not in the view of the planners of the systems.

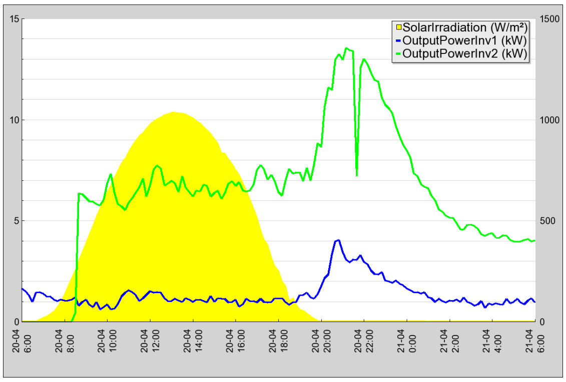


**Figure 12:** Solar irradiation and AC-output of the system Kesheng, 20.04.2006, clear day

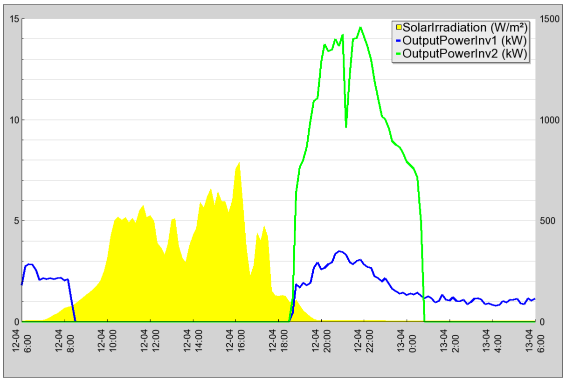


**Figure 13:** Solar irradiation and AC-output of the system Kesheng, 12.04.2006, cloudy day

- There is still room for system optimisation. Unnecessary parasitic losses of more than 5 % of the power delivered to the load might be avoided. Better instrumentation of the battery state of charge and clearer rules for the system operators might increase the utilization of the energy which is "theoretically" available (figure 14). Automatic energy management should make it possible – at the given system layout and today's consumption pattern – to provide a 24 h by 24 h supply for most days of the year.

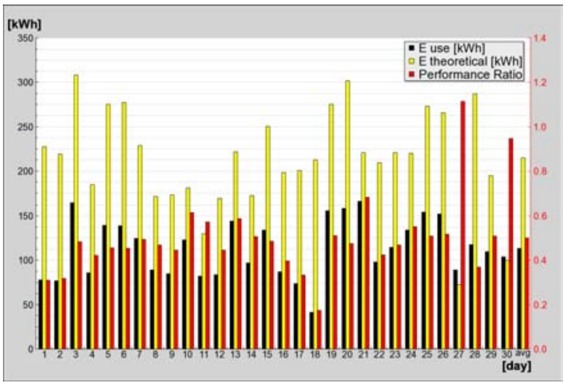


**Figure 14:** Daily values for utilized energy, nominal production and performance ratio, Kesheng, April 2006

- And finally it should be mentioned as a precaution, the short time of the evaluation does not yet confirm that the large batteries which have been installed are operated under conditions which will lead to long battery lifetimes.

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[Figure 2, 3, 4, 5, 6, 7, 8]
Photographs by Hansjörg Gabler, ZSW