MONITORING OF SOLAR HOME SYSTEMS IN CHINA: FIRST YEAR RESULTS

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Results are presented of the first year of monitoring solar home systems in three provinces in PR China. With a limited number of measured parameters the operation of the systems can be monitored thoroughly. The 45 Wp PV-modules are somewhat over-sized for lighting use only. Energy balances did not reveal any unnecessarily high system losses.
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1. INTRODUCTION

1.1 Background

Solar home systems have been installed in more than a million households in developing countries. For most users it is the only practical and affordable way to obtain access to electricity. A recent literature survey concluded that there is a severe lack of information about the performance of solar home systems [1]. This monitoring activity is targeted to deal with this problem.

Fig 1. PV-module of a solar home system with data logger (No.3) in Sahantala, Inner Mongolia. Note the portable structure which allows transporting the module.

1.2 Objectives

The aim of the monitoring work in China is to obtain quantitative information about the actual use of solar home systems. This knowledge is intended to provide inputs for improving the quality of components, design of the systems and implementation of projects. A more specific aim is to draw conclusions on the required capacity of the PV-module and the battery with respect to household demand.

The monitoring project is part of a larger government-supported program where a Dutch research institute and a solar module manufacturer work together with research institutes in three Chinese regions to transfer knowledge on the application of solar PV systems in rural electrification.

The monitored solar home systems have a 45 Wp multicrystalline silicon module, 100 Ah (C_{100}) solar battery (vented lead-acid), and a standard 8A charge controller. Each system has three 6 watt fluorescent lights.

All areas have a land climate, where Inner Mongolia is desert, Qinghai has some mountainous regions and Xinjiang has serious mountains at locations where the systems are installed. Latitudes vary from 43° north in both Inner Mongolia and Xinjiang, to 35° north in Qinghai.

2. DATA ACQUISTION

2.1 Choice of data logger

A small 5-channel, 8-bit logger was selected that fits into the battery box. With a registration interval of 30 minutes, more than 5 months of data can be stored in the logger. The small number of channels requires a careful selection which parameters will be monitored. Half-hourly averages are stored on irradiance, the PV-module current, the battery voltage, the current to the load, and the temperature in the battery box. Irradiance is measured with a reference cell.

2.2 Installation of data loggers and choice of households

Out of a total of 150 identical Solar Home Systems, 12 were equipped with a data logger (3 in Inner Mongolia, 4 in Qinghai and 5 in Xinjiang). Great care was exercised to minimise interference with the user, both technically and socially. The logger has been integrated inconspicuously in the battery/charge controller box of the Solar Home System. The systems that are logged are visually identical to the ones without data logger (with exception of the reference cell). The logger has its own power supply and does not sponge on the SHS. The locations chosen for the logged systems are remote and not exposed to official attention. No visitors are taken to these locations.

2.3 organisation of data acquisition

The Chinese partner institutes, with whom this project is carried out, planned to pay regular visits to the sites to collect the data using a laptop computer. Once collected, the data files are transferred by email. For future projects it is recommended, to use remote data collection (possibly by LEO satellite, as GSM coverage is not assured at all rural sites). The manual data collection is difficult to maintain due to bad road conditions in winter and the remote, often untraceable living sites of the users in summer.

2.4 Operation of the data loggers

Monitoring started in April 2000. To date, from eight of these systems data have been received. Only five systems gave useful insolation data. In three of the eight systems, the charge regulator was bypassed for at least part of the load, or part of the time. For these cases it is impossible to calculate energy balances with a break-down of the different loss-components in the system. As a result, only four data series were good enough to calculate an energy balance. In total the monitoring fraction was about 40%. Energy balances can be calculated for only 25% of the monitoring time.

3 RESULTS

3.1 Insolation

A typical graph of irradiance is shown in figure 2. For 48 half-hourly periods, the maximum value of the irradiance is given. From the shape of this curve it can be concluded that no substantial shading takes place. In the same graph also average load is presented. As in all systems monitored, almost all electricity is used during the evening. A continuous load of almost 1 watt is present in most of the systems, the cause of which is still unknown.

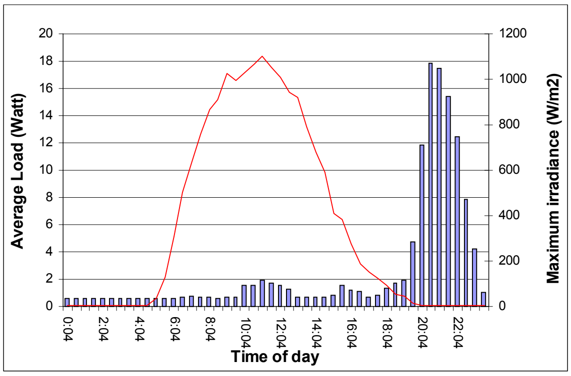

Figure 2. Maximum irradiance and average load over May 2000 for system 9 in Luo Buo Tai Zi in Xinjiang.

In figure 3, a similar graph is shown as in figure 2, but for a system in Guinan, Qinghai. Here the maximum irradiance curve shows an anomalous shape, with a much broader peak than with all other systems. A closer inspection of the daily irradiance curves (see fig. 4) reveals that the individual daily curves do not exhibit a broad maximum, but instead show two peaks. The PV-module is mounted on a portable frame (see fig. 1). Apparently, the owner of this system redirects the module to the sun during the day.

From none of the data loggers, insolation data of the whole month of December could be obtained. But the limited number of days with data show an average irradiation of about 2 kWh/m^2/day. During the summer months (May-August) all systems with data show daily average irradiation in the range of 5 to 7 kWh/m^2/day.

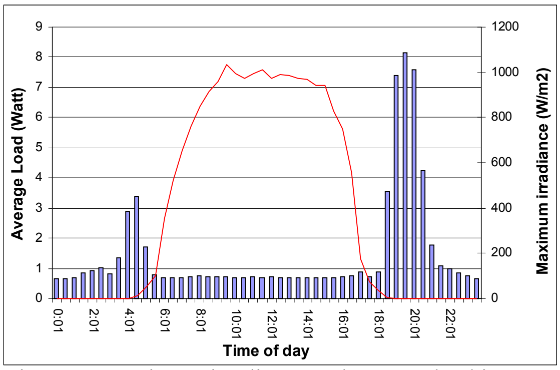

Figure 3. Maximum irradiance and average load in May 2000 for system 5. Compared to figure 2, the irradiance curve is much broader near the top.

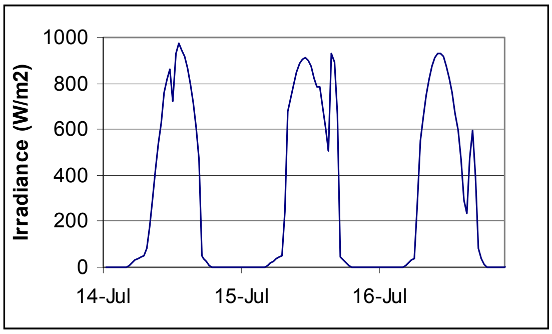

Figure 4. Irradiance graph for three consecutive days in 2000 for system 5. All three days show a distribution with two peaks, most probably caused by redirecting the module once a day. This explains the broad curve of figure 3.

3.2 High Voltage Disconnect

An important parameter in assessing the sizing of the system is the amount of time that the battery is full, as indicated by high voltage disconnect (HVD). Occurrence of HVD can not be measured directly with our data logger. Instead we inferred it from the relation between module current and irradiance (see fig. 5). When the battery is not full, a more or less linear relation exists between these two parameters. All points below the straight line indicate HVD. HVD occurs frequently in all systems with available insolation data.

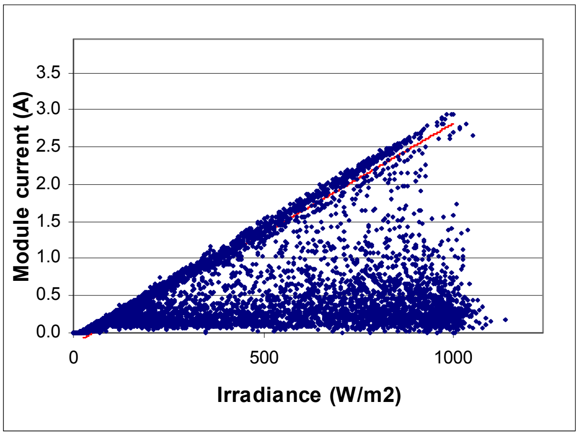

Figure 5. Irradiance versus module current for system 9. All the points below the straight line are supposed to indicate high voltage disconnect.

3.3 Temperature measurements

Within the data logger is a sensor for the temperature. Since the logger is located in the top of the battery box, it represents the ambient temperature. Information about temperature levels is relevant for studying the lifetime of the battery and other components. At the moment the monitoring time is much too short for such kind of analysis. But unexpected information was obtained. For a number of systems, the temperature graph showed sudden changes in daily fluctuations. An example is shown in figure 6, where these changes take place in early June and late October. At these times, the battery was disconnected for a short time. A light structure, such as a tent, would result in larger daily temperature fluctuations compared to a brick house, especially during clear days in the summer. The users are known to be herdsmen who move with their cattle occasionally.

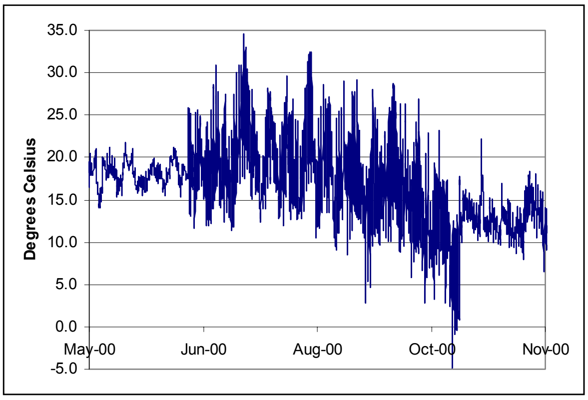

Figure 6. Temperature at the top of the battery box for system 9 over the period May to November 2000. Abrupt changes in the daily fluctuations are probably due to moving the system to a tent during the summer months.

The relation between ambient temperature and battery voltage is presented in figure 7. During charging the actual battery temperature can be a little higher than the ambient temperature. But on the whole, it will be close to the ambient temperature. The graph shows that the temperature correction of the HVD setting is working well.

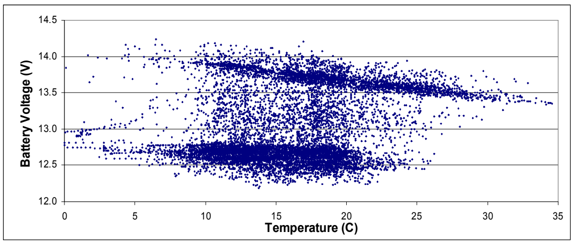

Figure 7. Ambient temperature versus battery voltage for system 9 from April to December 2000. The dots forming the inclined line at the top shows the temperature dependence of the high voltage disconnect setting.

3.4 Load

Only the total electricity consumed by the household is measured. However, from a load frequency distribution an indication can be obtained regarding the use of the different appliances. When the number of hours are counted in which a certain load level occurs, a plot with distinctive peaks result, due to the fact that there is only a limited number of appliances in use (typically three 6 watt lights). From figure 8 it can be concluded that this household either used three lights at the same time or only one light, but rarely two lights at the same time. None of the households kept a 6 Watt light on continuously during the night. Only in one case (No. 0), on top of the continuously present 1 Watt load, an additional 1 Watt is in use during the second half of the night. This could either be the 6 Watt light which is on for short periods only, averaging 10 minutes per hour, or they use a small 1 Watt night light.

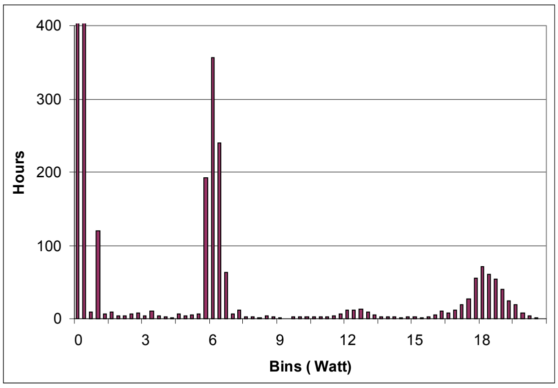

Figure 8 Load frequency distribution for system 7, showing the number of hours over the period June to November 2000 with a load within a range of 0.3 Watt bins.

3.5 Reference yield

Availability of insolation data allows one to calculate the reference yield (peak sun hours). In figure 9 monthly reference yield data are presented for system 9. In the same graph also the monthly final yield (load) is given. The lowest reference yield occurs when the load is at its maximum in the winter.

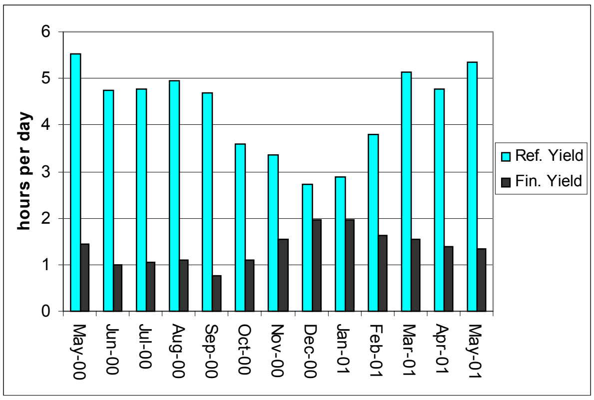

Figure 9. Reference yield and final yield (load) for system 9 for the period May 2000 to May 2001.

3.6 Energy balance

An important output of the monitoring exercise is the quantification of the main energy losses in the system. They fall in four categories, of which the first two are capture losses, and the other two are BOS losses.

a) Module related losses

Module power was calculated by multiplying the measured module current with the module voltage (calculated from the battery voltage and the voltage drop over the BCR), and scaling this to 1000 W/m^2. The difference with the nominal array power is caused by the combined effects of: dust on the module, differences between actual and nameplate capacity of the module, temperature effect, cable losses and operation outside the maximum power point. Our data does not allow us to distinguish between these individual items.

b) HVD losses

The difference between what could have been generated by the module (at times without HVD) and what is actually generated as measured via the module current (array yield), is supposed to be caused by high voltage disconnect losses.

c) Losses in the charge regulator

With the known (constant) voltage drops within the BCR and its own consumption one can calculate energy dissipation in the electronics.

d) Storage losses

Battery current is not measured directly. But with the known module and load currents it is possible to quantify net energy to the battery. In absence of changes in the battery state of charge this is equivalent to energy losses in the battery.

For system 9, monthly energy balances are presented in figure 10. The negative values of the storage losses in November and December are due to a decline in the battery state of charge. From the small level of HVD losses in December (15%) one can conclude that this system is somewhat oversized. Taking into account the fact that the storage capacity is not used completely, this system would have provided energy without loss of load with a module with a 15% smaller capacity. For two other systems with data over the months November and January this figure is 10%. With a 50% smaller module capacity in system 9, loss of load would occur mainly in December and January, and to a much smaller extent also in November and February. The total unmet demand for this system would then be about 10% of the annual energy demand.

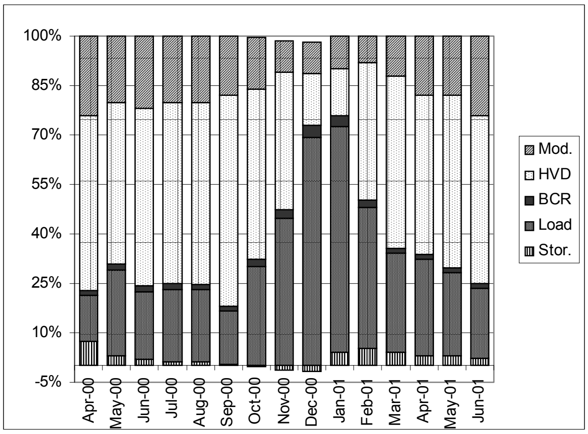

Figure 10. Energy balance of system 9 over the period April 2000 to June 2001. As a percentage of the reference yield the contribution is given of (from top to bottom): a) module losses, b) HVD losses, c) losses in the BCR d) net energy to load, e) net energy to storage.

4 CONCLUSIONS

All monitored solar home systems continue to operate without problems. Technically the data loggers worked well, but regular data collection was more difficult than expected.

Data quality

Insolation measurements are unreliable in a number of cases. The monitoring fraction is low due to difficulties in retrieving the data from remote areas. There are more data gaps than expected, and none of the data series is uninterrupted. Data retrieval for the winter months was perceived as a potential problem from the start, and this fear turned out to be justified. Extra effort will be required in the future to retrieve data in April or May.

Sizing

Due to strong seasonal variations in the electricity demand and supply, the systems are oversized for most of the year. Usually, solar home systems are applied in tropical areas with smaller seasonal insolation variations. Because of the required over-sizing of the PV-module, application of solar home systems in northern and western regions of China is less efficient from a resource-use point of view than in tropical areas. However, it can still be the most cost-effective solution for remote rural electrification due to lack of alternatives. An advantage of over-sizing will be a long life expectancy of the battery.

To meet current energy demand for lighting use only in the winter months, a module capacity of 35 to 40 Wp instead of 45 Wp would have been sufficient. Future television use throughout the year would require additional PV-power. With the current module size, a television can only be used when users are willing to accept that they cannot watch television in December and January.

Most systems presently available on the Chinese market in the investigated regions include 25 Wp modules. With this module size, sufficient energy would be available for most of the year. But about 40% of the energy demand in December and January, and 10% of the annual demand cannot be met. Users should be informed beforehand that this will occur, so that they can prepare themselves by rationalising energy use.

Losses

Only about one third of the reference yield of electricity is actually consumed by the user. Most of this apparent inefficient use of the system is caused by the need for over-sizing to cover the demand in winter months. Module losses range from more than 20% in summer to about 10% in winter, probably due to the changing contribution of the temperature effect. These figures suggest that there are no substantial losses that can be reduced easily by system designers.

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