Industrial Electrical Engineering and Automation

CODEN:LUTEDX/(TEIE-5156)/1-87/(2001)

# Batteries used within Solar Electric Systems in rural Uganda

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# Abstract

Solar electricity is one possible way to electrify rural Uganda. To convert, store and use the energy in the sunrays as electricity a solar electric system is utilized. Such a system for domestic use normally consists of a solar panel, load appliances, a charge controller and a lead-acid battery. These batteries are made up of lead and lead dioxide electrodes placed into electrolyte. Lead is a metal that poses extreme environmental hazards.

The objective of this thesis is to study ways to reduce the environmental impact of solar electric systems through prolonged life expectancy of the batteries and proper handling of worn-out ones.

Three types of field studies were carried out in Uganda; interviews with domestic end-users in rural areas combined with servicing their system, interviews with persons from different solar companies, and study visits and interviews with other stakeholders like the local battery producer and governmental authorities.

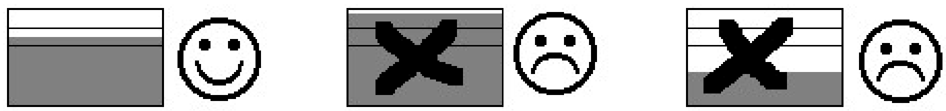
The field studies revealed many shortcomings in areas such as end-user training, maintenance, after-sale service and handling of worn-out batteries. Examples of low cost measures to prolong the life expectancy is to provide the end-user with a graphic maintenance manual, a bottle of distilled water and a battery box when installing a system. The solar companies have direct contact with the end-users and play an important role. The number of branch offices need to be increased to facilitate this contact, improve the after-sale service and the supply of spare parts. Another way to improve the companies' quality of work is to monitor them, provide more training for solar technicians and enforce standards.

Either should local production of batteries made for solar electricity applications be implemented, or the high import taxes removed. A bench test of different batteries is needed to compare prices with lifetimes. People are not aware of environmental hazards and health risks the batteries pose. The local producer of car batteries has the only lead recycling facility in Uganda. They accept only the amount of lead required in their production. Consequently scrap batteries are accumulated all over the country, mostly due to the car fleet but also due to solar electricity.

An example of a graphic maintenance manual. (See also Appendix E)

# Maintenance Manual for Solar Electric Systems

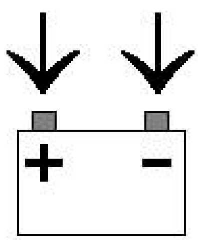
## THE BATTERY LEVEL



Check the battery level every 2 months. Top up if the level is beneath the lower level. USE DISTILLED OR DE-IONIZED WATER ONLY. Distilled water can be bought at any petrol station. DO NOT use tap water or battery acid!

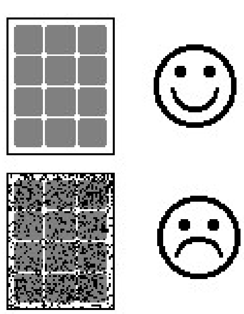

## THE BATTERY TERMINALS

PETROLEUM JELLY ☺ VASELINE ☺ GREASE ☹



Clean the terminals and put on petroleum jelly or vaseline. Do this every 2 months to prevent corrosion. DO NOT use grease!

## THE SOLAR PANEL:



The solar panel should not be dirty or dusty. Clean it every 3 months with a soft piece of cloth and clean water. DO NOT use soap and make sure not to scratch the panel.

Installing company:......................................

Contact number:.............................................

# Acknowledgements

I want to thank my boda-boda driver, guide, technical assistant, brainstorming fellow and close friend Edward “Hardman” Kyalimpa for his assistance in the rural areas of Uganda. Without him it would have been very difficult to fully understand and obtain all the information I got.

I have had a number of both formal and informal supervisors that all has encouraged and supported me in different ways. Dr. Mackay Okure, Makerere University, has guided me in the jungle of Ugandan bureaucracy, introduced me to the solar electric market, and spurred me throughout my stay in Uganda. Dr. Olof Samuelsson, Industrial Electrical Engineering and Automation (IEA), has encouraged and given me valuable advice before, during and after the field studies, not to mention his careful proofreading of this thesis. I am also very thankful for his ability to give free rein. Prof. Gustaf Olsson’s (IEA) ability to put things in perspective has improved this thesis considerably, as well as his proofreading and valuable comments. Furthermore I am grateful for all conceivable practical advice that Prof. Lars Gertmar (IEA) has provided.

Sten Bergman, senior energy specialist at the World Bank, initiated the project and has given me support along the way.

The World Bank, Elforsk and ABB Corporate Research have financially supported this work. The latter also provided me with a laptop, which has facilitated things enormously.

Finally I would like to thank all people in rural Uganda that I have interviewed, talked and discussed with during my stay. This thesis is for you.

*Annamaria Sandgren*

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# 1 Introduction

Two urgent energy issues in Uganda of today are rural electrification and development of renewable energy sources. In 1998 The World Bank, together with the Nordic aid organizations, started Africa Rural & Renewable Energy Initiative (AFRREI) to pace up the energy supply for the 400 millions of people living south of Sahara with no access to electricity (see figure 1). One of the first programs to be carried out is one in Uganda, Energy for Rural Transformation (ERT). The aim of this program is to increase the extent of rural electrification from 1% to 10% in 10 years, and at the same time extend small-scale renewable energy production to about 70 MW. Included in this program is a component based on solar electricity.

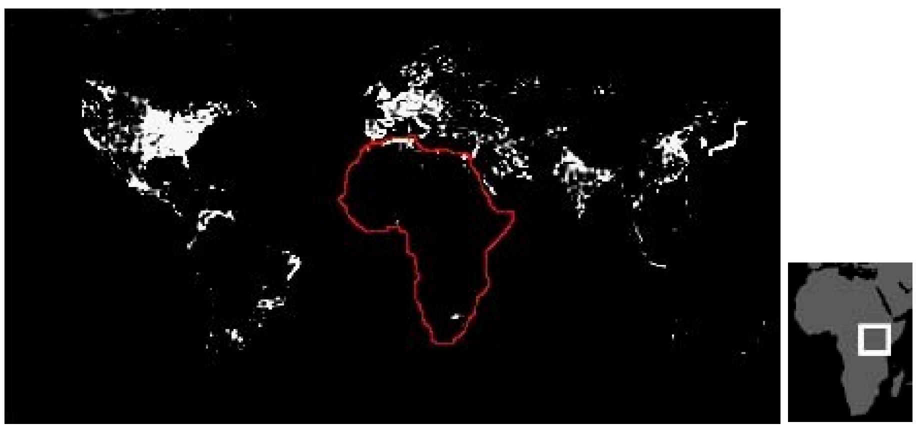

Figure 1: The large image is a composite of hundreds of nighttime photographs of the earth, and clearly shows which areas of the world are electrified. The contour line of Africa of is marked red and the position of Uganda is indicated in the small image on the left. (Modified from C. Mayhew and R. Simmon (NASA/GSFC), NOAA/NGDC, DMSP Digital Archive)

Solar electricity is an appealing solution since there is no need for fuel and little need for maintenance. Electricity is produced daytime while it is consumed mainly after dark. This requires storage of energy, and today lead-acid batteries are at use. Lead-acid batteries contain a lot of lead, which is a metal that poses extreme environmental hazards. Consequently two aspects are important to minimize the environmental impact. One is to prolong the life expectancy of the batteries, which both reduces operating costs and improves environmental performance, since long-lived batteries do not have to be replaced as often as short-lived ones. Another is to secure proper handling of worn-out batteries.

The objective of this project is to assess technical and environmental aspects of batteries used within solar electric systems in rural Uganda. In greater detail ways of prolonging the life expectancy of the batteries will be studied, along with the handling of worn-out batteries. The focus is on household applications, and mainly practical solutions are considered.

Chapter 2 and 3 introduce the reader to the general technologies of solar electricity and lead-acid batteries. Advantages and disadvantages are discussed and environmental issues and maintenance requirements are outlined. In chapter 4 the present situation of solar electricity in Uganda is described, a cost analysis is made and stakeholders are introduced. Three kinds of field studies were done in this study; interviews with end-users in rural areas combined with servicing their system, interviews with persons from different solar companies, and study visits and interviews with other stakeholders. Approaches and methodologies for these field studies are outlined in chapter 5 together with a review of the actual findings. The field studies revealed practical problems and shortcomings in maintenance and after-sale service, not to mention lack of proper storage and recycling of worn-out batteries. All this is evaluated, and discussed in chapter 6, which also contains suggestions for improvements. The final chapter (7) is a dense summary of recommendations. The very last page of this thesis contains a list of abbreviations to facilitate the reading.

# 2 Solar Electricity

The sun is the source of virtually all energy on earth. It provides energy for the photosynthesis, is the engine for all wind and rain, and warms up the atmosphere. Indirectly we harvest the energy from the sun when we use fossil fuels, firewood, hydroelectricity, wind energy, and even when we eat our food. By using solar cells we can convert the solar energy directly to electric energy, so-called *solar electricity*. This technology is relatively new and it is making electricity available wherever sunlight quantity permits. This chapter gives a short introduction to solar electric systems, followed by a summary of the advantages and limitations of this technology.

## *2.1 An introduction to solar electric systems*

To be able to harvest, store and use the energy in the sunrays, there is need for a set of electrical devices combined into a *solar electric system*. These systems can differ from each other and be of various sizes. This study only deals with the smaller systems, which are primarily used by private households. In the following sections a short description of the different devices used in such a system is made. (See figure 2)

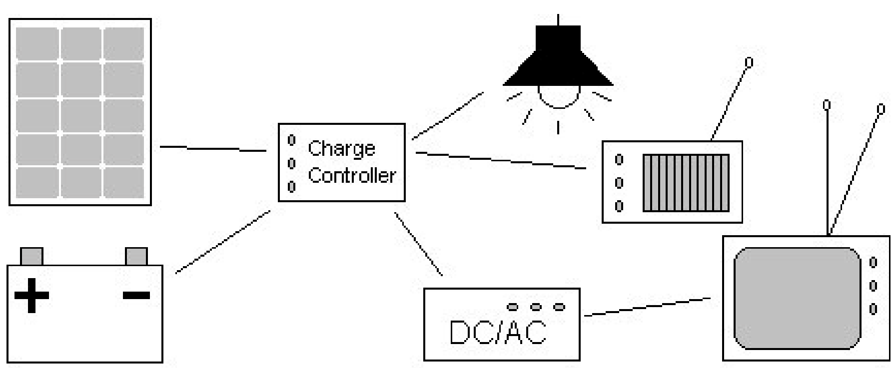


Figure 2: An example of the components in a solar electric system.

## The solar panel

*The solar panel* is the device in the solar electric system that converts the energy in the sunlight into electric power. This is done through a physical phenomenon called the photovoltaic (PV) effect. The size of the panels is rated accordingly to their maximum power output. This is the maximum number of Watts a panel can produce for optimum external conditions in terms of temperature, irradiation, etc. The unit for this peak power output is Watt peak (Wp). The panel has to be clean from dust and mounted at the optimal angle to maximise the output. Still, in field conditions the actual output is always lower than the rated Wp.

## The electric load

Fluorescent tubes, radios, and black and white televisions typically represent *the electric load* in a small solar electric system used in households (Hankins 1995 p. 22). Most of the time the appliances are of the energy saving type and run on DC current. Refrigerators, computers and colour televisions are also possible to connect, though they consume relatively much power and consequently require panels of a higher capacity that are more costly. Unfortunately cooking and ironing require too much energy to run on solar electricity under normal conditions (Louineau 1998 p. 5).

## The battery

There is need to store the energy collected by the panels during sunny days for use at night and cloudy days. In almost all PV systems a rechargeable *lead-acid battery* is the most common device used as storage. There are many different types of lead-acid batteries ranging from ordinary cheap car batteries to the more sophisticated deep cycled solar batteries. More detailed information on batteries is given in chapter 3.

## The charge controller

*The charge controller* is the brain of the system. Since the energy collected by the panels is limited, and the battery must be protected from being totally discharged or overcharged, there is need to control the system so that the electricity that is produced balances the amount consumed.

### The inverter

The panel only produces direct current (DC). Some kinds of load such as colour televisions and computers require alternating current (AC) to function. Consequently there is sometimes need for a device that converts DC to AC, a so-called *DC/AC inverter*.

### Sizing

To combine these components into a solar electric system is not a simple task. The different components need to balance each other. The procedure of calculating needed power and the appropriate component sizes is called *sizing*. There are many factors to consider such as incoming solar irradiance, seasonal changes, daily energy use, panel capacity and battery size.

## *2.2 Advantages and disadvantages of solar electricity*

Like all technologies solar electricity has both limitations and opportunities. In this section the most important pros and cons are outlined.

An important advantage with solar electricity is that it makes electricity available also in remote areas; there is no need to wait for the extension of the electric grid to get good light, radio and TV. In Uganda this is of great importance, since some rural areas will probably not have access to the grid for many decades. The disadvantage is that, even if electricity is made available, it is very limited in terms of power. Activities that consume a lot of power, like cooking and ironing, cannot run on solar power (Louineau 1998 p. 5).

Another important aspect is the profile of the lifetime costs. The investment for a solar electric system is high, and the operating costs are low. Even if the expenses for the total lifetime are less than buying kerosene, candles and dry cells for the same time period, the high investment cost act as a barrier (Shirzadi 2000 p. 2).

Maintenance requirements are low compared to other similar conventional energy sources, like diesel generators (Louineau 1998 p. 5), but the need for maintenance cannot be neglected. Only if a system is well cared for it will last for the supposed 20 years. Solar technicians are needed once in a while and the end-users need to check the battery and clean the panel.

# 3 The Battery

Even though solar electricity is a modern technology it involves a number of conventional devices. Surprisingly experience shows that it is not the solar panel that causes problems. On the contrary well tried out components are often responsible for failures. The battery is one conventional device that often fails. The reason for this is the unfavourable operational condition of randomised charging and discharging patterns the battery is exposed to (Lorenzo 1994 p. 115). The lead-acid battery therefore has shorter life expectancy in solar electric systems than in traditional applications. The low-price car batteries often used in solar home systems normally have to be replaced after 2-3 years (Bopp et al 1998 p. 275). Since the life expectancy of the complete solar system is about 20 years the total battery cost is significant, and it is good value to spend time and money to prevent unnecessary ageing and breakdowns.

## *3.1 Operating principles*

A rechargable battery is principally made up of one positive and one negative electrode placed in electrolyte. In a rechargable lead-acid battery the electrolyte consists of sulphuric acid ($H_2SO_4$) diluted in water, the postive electrode is made of lead dioxide ($PbO_2$) and the negative of lead (Pb).

During *discharging* the electrochemical energy stored in the batteries is consumed as electric power. In the chemical process sulphuric acid is absorbed from the electrolyte and lead sulphate ($PbSO_4$) is formed at both electrodes (see figure 3).

The reverse reaction takes place during *charging*, when electric power is transformed and stored electrochemically in the battery. Lead is formed at the positive electrode and lead dioxide at the negative, while sulphuric acid is released to the electrolyte (see figure 3). (Hankins 1995 p. 41)

$$\mathbf{PbO_2 + Pb + 2H_2SO_4} \underset{\textit{charge}}{\overset{\textit{discharge}}{\rightleftarrows}} \mathbf{2PbSO_4 + 2H_2O}$$

Figure 3: The chemical reactions taking place in a lead-acid battery.

If the battery is fully charged and the charging power is not disconnected the water will be electrolysed into oxygen and hydrogen gas. This process is called *gassing*, and since the gases escape into the air water is lost (Lorenzo 1994 p. 122).

## 3.2 Construction of the battery

Though the principle of the lead-acid battery is simple and easily comprehended, the construction of today's batteries is more complicated. Of course there are a number of various practical designs and different types of lead-acid batteries. But, there are some components that most types have in common. In this section a presentation of these (see figure 4) is made.

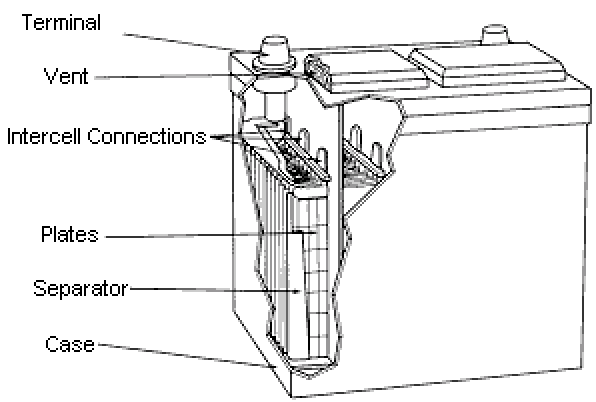


Figure 4: The principal components in a typical lead-acid battery.

The electrodes mentioned above are shaped as thin *plates* (see figure 4) and each consists of two parts, the *grid* and the *active material.* The grid is made of solid lead and serves both as a mechanical support and as a conductor of the current. It contains a porous sponge, the active material, made of lead at the negative electrode and lead dioxide at the positive. This is where the chemical reactions take place. The active material increases the electrochemically active area, facilitates the penetration of electrolyte and speeds up charging and discharging. A number of plates are placed next to each other, alternately positive and negative. To hinder the plates from making electrical contact a porous plastic material is placed between them. These, so called *separators* (see figure 4), allow the electrolyte to flow freely, but prevent short circuits. (Lorenzo 1994 p. 118-119)

A battery can be made up of one or several *cells* and each lead-acid battery cell, when fully charged, has an output around 2 V. For instance in a 12 V lead-acid battery there are 6 cells connected in series by inter-cell connections. The cells have different characteristics and the battery is never better than the worst cell. Variations can also deteriorate with time, and so-called equalisation charges can be performed once in a while to prevent this. These consist in a moderate overcharge to bring all the cells to the same state. (Lorenzo 1994 p. 138)

The *electrolyte* can either be liquid as in so-called flooded batteries, or in gel form as in gel batteries. This study is only dealing with flooded batteries and they are consequently the only ones described here. The electrolyte, as mentioned above, consists of sulphuric acid ($H_2SO_4$) diluted in water. When a battery is fully charged all the sulphate ions are in the electrolyte, and when the battery is uncharged the active material has absorbed most of them. The density, also called *specific gravity*, of sulphuric acid is higher than that of water. Accordingly the specific gravity is high when the battery is charged and low when it is uncharged. This is utilized to measure the state of charge in each cell. The specific gravity is measured and converted into the equivalent State Of Charge (SOC) with the help of a table (see table 1) or graph. (Hankins 1995 p. 46)

**Table 1: SOC vs. Specific Gravity for a Kenyan solar battery**
(Hankins 1995 p. 46)

| State of Charge (%) | Open circuit Voltage (V) | Specific Gravity (grams/litre, 25°) |
|---|---|---|
| 100 | 12.74 | 1230 |
| 90 | 12.62 | 1216 |
| 80 | 12.50 | 1203 |
| 70 | 12.36 | 1189 |
| 60 | 12.25 | 1175 |
| 50 | 12.13 | 1161 |
| 40 | 12.00 | 1147 |
| 30 | 11.87 | 1134 |
| 20 | 11.75 | 1120 |
| 10 | 11.64 | n/a |
| 0 | 11.51 | n/a |

There are two *battery terminals* (see figure 4), one negative and one positive, that are utilized as electrical contacts. The cells are put together in a *case* made of plastic, containing one chamber for each cell. Each cell has cap with a one-way *vent hole*, so that if gassing occurs the oxygen and hydrogen escape easily without forming the explosive oxyhydrogen gas.

When lead or lead dioxide is transformed to lead sulphate during discharging the volume of the active material increases 2-3 times. This causes mechanical stress to the grid and active material can loosen from the plates, and become useless to the operation of the battery. This phenomenon occurs especially at the positive plates. To solve this problem in frequently discharged batteries (like in photovoltaic applications) *tubes* have been developed. These tubes, made of plastic or fibreglass, cover the positive plates and prevent losses of the active material while letting the electrolyte pass trough. Not all kinds of lead-acid batteries contain these tubes. (Lorenzo 1994 p. 120)

## 3.3 Environmental issues and health concerns

Lead has always been present in the environment and also in man, but human activities have increased the quantity drastically. Inhalation of lead dust and ingestion of contaminated water, soil and food are the two most common ways of intake for man. Lead contamination causes very general and unspecific symptoms and it can be hard to diagnose. But one early effect of high levels of lead contamination in the blood (>80 • g/dl) is anaemia, of which the early symptoms are fatigue, headache and lassitude. Prolonged lead exposure may produce effects on the Central Nervous System, with symptoms like physiological and behavioural changes. This effect is much more important to children, as symptoms may occur even at very low blood levels (10 • g/dl). (Guidelines 2001 p. 32-35)

The electrolyte is made up of sulphuric acid, which can eat its way through clothes and skin, and has an adverse affect on the environment. In addition the electrolyte in an old battery is highly contaminated with lead particles. Lead in an acidic environment is relatively easily transported in soil (Jensen et al 2000 p. 367-379), and consequently can these lead particles reach drinking water supplies and arable land relatively easy if the electrolyte is poured out.

Another health concern considering lead-acid batteries is the risk of explosion. When a battery is being overcharged and gassing occurs the gases are supposed to escape through the vent-holes (see figure 4). If they happen to be clogged there is risk for an explosion. For that reason it is important to keep the battery in a lockable and empty room, or in a battery box. This also prevents the risk of electric shock to people and animals.

## 3.4 Battery maintenance and some practical considerations

A lead-acid battery has a distinct ageing process (Bopp et al 1998 p. 280) and has to be changed sooner or later. But there are some very simple maintenance activities and practical considerations that can prolong the lifetime and improve the efficiency of the battery radically.

The amount of acid in the electrolyte is constant and the acid concentration only varies with the amount of water and the state of charge. The optimum concentration for a fully charged battery ranges from 1.20-1.28 g/cm$^3$, depending on type and brand (Lorenzo 1994 p. 119). Due to evaporation and gassing there is always some loss of water from the electrolyte. If the loss is severe, the plates are exposed to air and will oxidize and cause breakdown. Consequently the electrolyte level should always be well above the plates and this needs to be checked every 2-3 months. Whenever needed the battery should be topped up with distilled water. (Hankins 1995 p. 50) To simplify the checking and topping up, most of the batteries have marks on the battery case indicating acceptable upper and lower electrolyte level.

The battery terminals should be firmly connected to avoid unnecessary losses. To prevent corrosion the terminals should be cleaned and pasted with petroleum jelly or Vaseline once in a while. The battery should never be disconnected from the charge controller without first disconnecting the panel, otherwise there is a risk that the charge controller will break. To prolong the lifetime of the battery it should be kept out of direct sunlight in a cool, clean environment.

## 3.5 Different types of lead-acid batteries

There are several different types of lead-acid batteries and in this section an outline of the battery types and their advantages and disadvantages in PV-applications are made.

*Solar batteries* are specially designed for PV-applications and can be deeply cycled. The positive plate is often made up of tubes and most of the time there is a large reserve of electrolyte to prolong the period between maintenance. Plenty of space under the plates is needed for loose material to accumulate without short-circuiting the battery. A lifetime around 10 years can be expected from solar batteries. The disadvantage is that it is difficult, sometimes impossible to obtain them in developing countries. They are very expensive compared to the conventional batteries mentioned below. (Lorenzo 1994 p. 133-135)

*Car batteries* are mainly used for starting up vehicles. They are also called SLI-batteries (Starting, Lightning and Ignition) or auto batteries. The battery construction is simple. As a consequence they are cheap to produce and purchase. Its construction allows large currents for short time periods, but the battery has low resistance to cycling. Since durability under cycling is required in PV-applications car batteries are not a very good option in solar systems. Still they are used in many developing countries where cost is a more important consideration than reliability. If car batteries are used in PV-applications large capacities should be chosen so that the average daily discharge does not exceed 10% of the total capacity. (Lorenzo 1994 p. 133-135) So-called *truck batteries* are the same kind of battery as the car battery. The only difference is the size. Truck batteries are much bigger to be able to provide enough power to start a big engine in a truck.

In some developing countries so-called *modified car batteries* are produced locally. These batteries are actually car batteries, but slightly modified to resist cycling a bit better. The lead content is higher and the electrolyte reserve larger. No great changes are needed in the manufacture line, so batteries more resistant to cycling can be produced without major investments.

*Traction batteries* are designed to supply energy for electric vehicles and trolleys. They manage deep and frequent cycling, but require some maintenance due to loss of water. Traction batteries are a good option for PV-applications if the needed maintenance is conducted. The main drawback is the relatively high cost and that they have to be imported to developing countries. (Lorenzo 1994 p. 133-135)

*Stationary batteries* are generally designed for un-interruptible power supplies. They require little maintenance, but are not advisable to use in regular PV-applications. An exception is in emergency applications where the cycling pattern is quite different. (Lorenzo 1994 p. 133-135)

# 4 Solar Electricity in Uganda

The potential for solar technology in Uganda is today largely untapped. Few systems are sold, prices are high and the technical capacity is limited. To address this issue a network for the solar market is being set up, including laws and regulations, financing mechanisms, taxes, standards and corporation between different companies and branches. In this chapter a description is made of the situation in rural Uganda regarding solar electricity, followed by an outline of the stakeholders involved in the network.

## *4.1 Cost analysis and dissemination*

It is unclear exactly how many systems that have been installed in rural Uganda so far. The documentation is often concealed regarding systems installed by companies, and non-existing when it comes to systems being purchased and installed by the end-users themselves. But it is clear that the solar technology is in its infancy in Uganda and the number of systems in the rural areas is most likely a couple of thousands.

The greatest barrier to ownership of a solar electric system among the rural population is probably the high initial cost. It is very difficult for most people in rural Uganda to accumulate enough money for the investment. In addition credit mechanisms are few or non-existing. Furthermore it is expensive to buy a system in Uganda compared to the world market price, in fact twice as expensive as in Europe. This is mainly due to high transportation costs, import taxes and high dealer margins. To be able to obtain large-scale cost reductions it is necessary to have a high dissemination of systems and there have been some advertising campaigns to achieve this. This has generated some interest, but this is not the same as demand. Interest has to be combined with spending power to appear as demand on the market. Consequently some kind of financial support is needed at an initial stage, combined with a proper supplying network. (Shirzadi 2000 p. 2-5)

## 4.2 Stakeholders

The supplying network in Uganda consists of many stakeholders; governmental authorities, private companies like battery producers and solar companies, and Non-Governmental Organisations (NGOs). They all play different roles and have different interests. In this section important stakeholders are described.

### Governmental Authorities

*The Ministry of Energy and Mineral Development* (MEMD) is running a project called the *Uganda Photovoltaic Pilot Project for Rural Electrification* (UPPPRE). It is a project supported by United Nations Developing Programme/Global Environment Facility (UNDP/GEF) and it is preparatory for the electrification program ERT. The objective of UPPPRE is to found the base for sustainable use of PV technology in rural areas, thus to facilitate the dissemination of PV. The target group is those that have the ability and willingness to pay the market price for the systems.

*The National Environment Management Authority* (NEMA) was established in 1995. It is the agency responsible for management of environmental issues and has the mandate to coordinate, monitor and supervise all environmental activities. NEMA has compiled an *arrangement of regulations* about waste management, including sorting, disposal, treatment and transportation of hazardous waste. In its fifth schedule it is defined which waste that is considered to be hazardous. Listed there is waste containing 0.1% or more (by weight) of lead and/or lead compounds. Consequently lead-acid batteries are considered to be hazardous waste and should be treated according to the regulations. (Statutory Instruments Supplement 1999 p. 261, 268-269)

*The Uganda Revenue Authority* (URA) is in charge of tax collection and customs. Thus URA plays an important role in import duties and taxation of PV products. At the moment the tax on complete solar electric systems (including one battery per system) is 17%, but the tax is 48% if just the battery is imported (Mabonga-Mwisaka 2001). URA is also involved in import and export of hazardous waste, both regarding the amount of tax and the actual storage of confiscated smuggled goods. (Country profile-Uganda 2001 p. 8)

*Uganda National Bureau of Standards* (UNBS) establishes national standards and minimal warranties in Uganda. For solar electric systems UNBS has set up standards regarding installation (Code of Practice for Installation of Photovoltaic Systems 2000), fluorescent lights and junction boxes. All these standards have compulsory legal status, but it is still unclear how the enforcement will be implemented. In progress are also standards for batteries used in PV systems. UNBS has some laboratory facilities, including testing equipment for electrical cables and meters. (Okumu 2001)

## Solar Companies

The last few years the number of PV dealers in Uganda has increased from two to about thirty (Da Silva et al 2001 p. 187). Since the market is far from stabilized it is difficult to predict the future, but today there are a number of quite established companies that sell and install PV systems. They all have their main offices in the capital city Kampala, and some also have a couple of branch offices in rural areas. A typical number of employees would be around 10.

*The Uganda Renewable Energy Association* (UREA) has been established by MEMD. It is an umbrella organisation for PV dealers, manufacturers, NGOs, etc. The association is enabling cooperation in common interests and acting as the unanimous voice of the suppliers. The association's task is to promote renewable energy, lobby for fair taxation, sound competition and good quality products (Mabonga-Mwisaka 2001).

## Uganda Batteries Ltd

*Uganda Batteries Ltd* (UBL) is the only local producer of lead-acid batteries in Uganda. Originally they only produced regular car batteries for the automotive market, but recently they started to manufacture so called modified car batteries. The galvanic cells in these batteries contain more lead and resist cycling a bit better then car batteries. These modified batteries are still a small fraction of the total production though, since there are many more cars in Uganda than PV systems. UBL is ISO (International Organization for Standardization) 9000 certified, which means they have implemented procedures to improve the quality of their products.

UBL also has the only recycling facility for lead-acid batteries. They recycle lead from scrap batteries to use in the production. The compensation for worn-out batteries is 185 USh/kg battery of which the electrolyte has been poured out and 230 USh/kg for just the plates (the case removed). This is equivalent to 0.11 and 0.13 USD respectively. The efficiency of the recycling process is approximately 70% and UBL can only utilize recycled lead for the negative plates, due to the relatively high degree of purity required for the positive plates (Sendagala 2001).

## Battery Charging Stations

Around the country there are a good number of small private *Battery Charging Stations*. A person has set up a diesel generator or has a grid connection that is used as energy source to charge a set of lead-acid batteries. Many owners of a PV-system take their battery for boost charging or repair once in a while.

## Institutions

One way to provide solar electricity to a broad range of people, independent of wealth, is to go through institutions like hospitals and schools. All end-users visiting these institutions can then benefit from solar electricity. These systems are often relatively big and most of the times have to be donor financed and project based.

## Non-Governmental Organisations

Many NGOs are acting on the PV market, as for example, financial supporters, environmental movements, and in educational purposes. *Uganda Rural Development Training* (URDT) is one NGO that plays an important role, it is both selling and installing systems and offering training for solar technicians. Also worth mentioning is *Uganda Environmental Protection Forum*, called Forum, a smaller NGO, engaged in management of solid waste. Forum has looked into the possibility of collecting and recycling lead-acid batteries in some districts in Uganda.

# 5 Field Studies

Three types of field studies were carried out in Uganda; interviews with domestic end-users in rural areas combined with servicing their system, interviews with persons from different solar companies, and study visits and interviews with other stakeholders like UBL and Governmental Authorities. The emphasis of the fieldwork was laid on the interviews with the households and that was also the first kind of field study to be realized. The other types were done later on and were more or less complementary. As a consequence a more extensive review is given on the household interviews, compared to those with solar companies and other stakeholders.

## *5.1 Approach and methodology for household interviews*

The solar technology is in its infancy in Uganda. There are only few solar electric systems, and they are widely scattered around the country. In addition it may be difficult to locate and access them. Although the systems are few, there are some areas where the density is relatively high. Clearly it is an advantage to carry out studies in such areas, since it is easier to accomplish a good number of interviews and accordingly get a selection that is more representative. Moreover it is interesting to know how the framework in terms of maintenance, after-sale service, supply of spare-parts, etc. is functioning where the density is high. With many systems around the true weaknesses are revealed, rather than problems related to the rarity of systems. These problems are not relevant and will disappear automatically if the number increases. Four districts were identified as suitable for this study: Kibale, Bushenyi, Rukungiri and Mbale (see figure 5). These areas all have a relatively high density of solar electric systems.

To be able to easily evaluate the answers from the interviews a *survey form for households* was compiled (see Appendix A). The batteries are the weak link in a solar electric system and this study is focusing on them. But since many of the battery failures have other primary causes than the battery itself, many external considerations have been taken into account in the survey form. The form is dealing with several issues, including end-user training, awareness, recycling, after-sale service, financing details, battery condition and end-user maintenance.

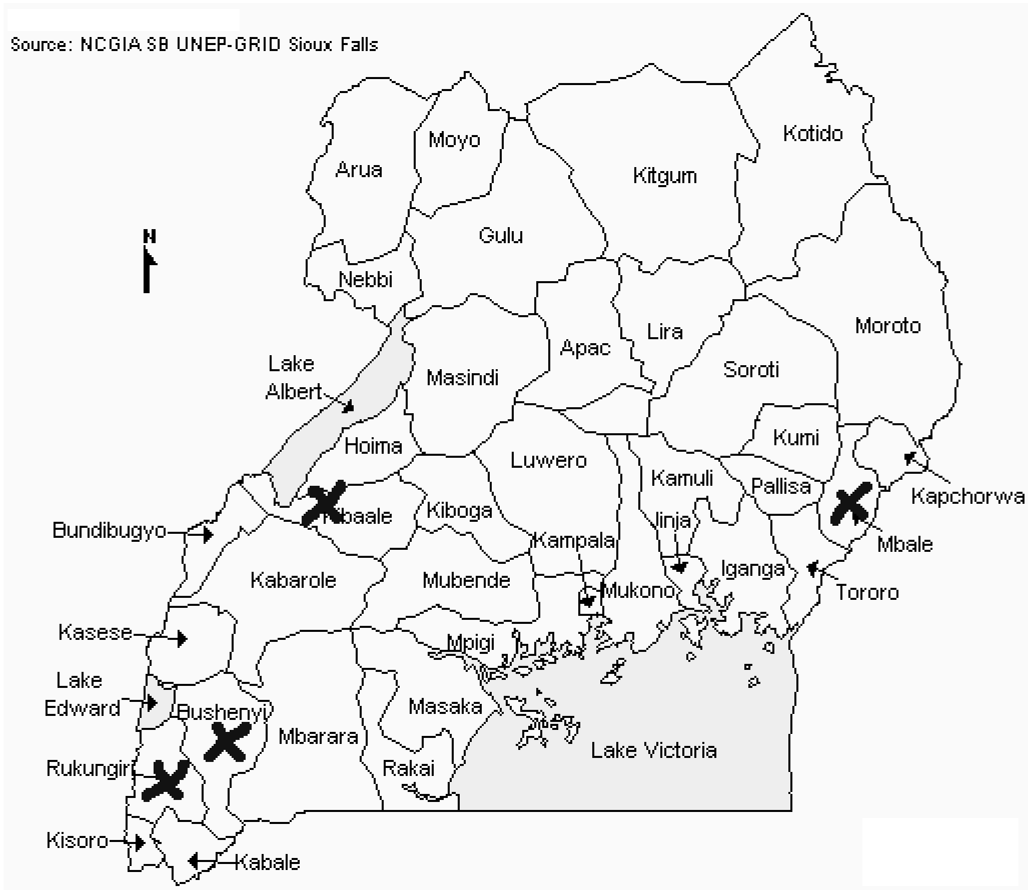

Figure 5: A map of Uganda where X marks the rural districts visited in the field studies.

To overcome difficulties such as speaking and understanding the local language, cultural clashes and lack of technical experience a local solar technician was hired to come along to the rural areas.

The systems visited were chosen randomly, i.e. independently of for example installing company, system size and owner. Village people were asked if they knew anyone around having a solar electric system and if they could describe how to get there. In most cases this method was proven successful. In addition the visits were unannounced. Generally it did not cause any problems, but sometimes it happened that the person best informed about the system was not at home.

At site the survey form was used as a tool to obtain information combined with servicing the system (see figure 6). The author both asked the questions and filled in the answers to make sure all questions were understood clearly and to simplify a sensitive description. The possibility to offer technical service to the end-users gave a strong incentive to get sufficient and correct information. Problems, reflections and wanted improvements were revealed as a natural spin-off. In addition an inspection of the battery location was easily justified and facilitated the check of the battery condition.

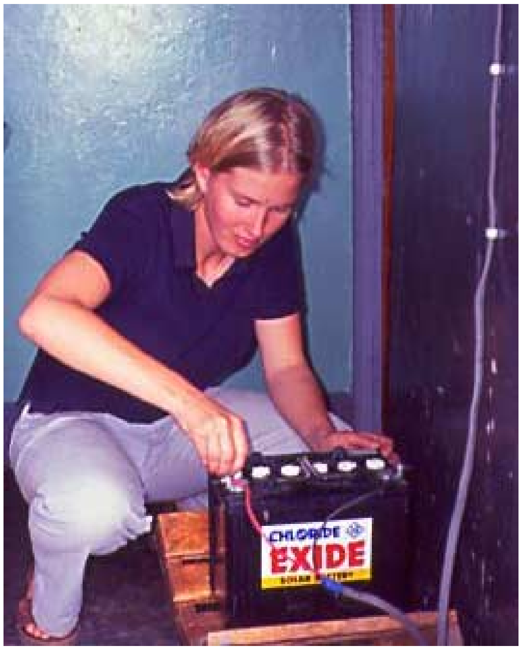


Figure 6: Annamaria about to check the battery condition. (Photo from field study)

## 5.2 Findings from household interviews

The findings and answers from the rural survey were put together and arranged into subject fields, to give a clear overview (see Appendix B). In the following sections some of these subject fields are utilized as subheadings.

### General information about the systems

All the systems included in this survey happened to be installed 1996 or later. This indicates how young the solar technology actually is in Uganda. Furthermore, it is resulting in a study only evaluating the actual launching of solar electrification program.

A typical PV system in the rural areas provides about 0.5 kWh per day. This is sufficient power to run some DC-lights of the energy saving type, one radio and one small black and white TV for a couple of hours every day.

## Financing details

The unsubsidized price of a solar electric system is very expensive. To purchase and install a system providing about 0.5 kWh costs about 1 000 000 USh (= 600 USD). This is equivalent to the average annual income of a rural household in Uganda (Shirzadi 2000). The households visited had an average income three times as high as this number. In cases where the income was relatively low, it was very often a well-off relative that had paid for the system.

In addition to the high investment costs, the credit conditions offered by the solar companies generally are very severe, typically 50-70% down payment and 4-6 months payback time. A significant share of the households had not paid off in time and had paid additional penalties, or like in some few cases had had their system confiscated. Where NGOs had been involved in installation and/or funding the credit terms were a bit more favorable.

## Information from installer

Common marketing channels for solar electricity are: word of mouth, radio adverts and demonstrations held by solar companies or NGOs. Generally, the marketing is not very aggressive and frequent, and the awareness of solar power as an option for rural electrification is relatively low.

In some cases technicians from solar companies had told customers that cooking and ironing relatively easy could be powered by a PV system. They were advised to start off with lights, radio and TV in order to add panels for cooking and ironing later on. These hoodwinked customers were really disappointed to learn that cooking and ironing was beyond the capability of solar electricity.

About a third of the households visited were not aware about the one-year guarantee that is given on the installation. The Ugandan law prescribes this guarantee in standards compiled by UNBS. On the whole, consumer rights are not very well established in Uganda and the awareness is very low.

## End-user training and maintenance

Almost all of the households had received some sort of training or instructions about their system and its needed maintenance. Two types of end-user training were dominating; training given by the solar technician when installing the system, and training given as a seminar by an NGO. In both cases it was primarily oral, given once, and only to one person (mostly the husband) in the household.

Regarding the instructions given on battery maintenance less then a third could correctly specify the needed activities without being reminded. Common misunderstandings were that the battery either should be topped up with sulphuric acid, or that the electrolyte should be changed once in a while. The lack of knowledge was also confirmed by relative poor or faulty battery maintenance. In some cases the installing technician had left behind a written piece of instructions, which, when it was simple and had been read by the end-users, had been of great help.

Few end-users knew they were supposed to clean the panel from dust, and even fewer had actually done so. A good thing is that the relatively frequent rains rinsed off most of the dust from the slightly tilted panels.

## After-sale service

The majority of the people asked consider it to be relatively easy to get hold of a technician, and the given waiting times (all but one less then a week) confirm this. But, one fourth of the households visited have had poor service done to the system or had been given misleading advice. For example, charge controllers had been bypassed (see figure 7), thin wires had been put in, extra load had been added without extending the panel capacity, fuses were replaced with metal thread, and the electrolyte had been changed in batteries. Both trained solar technicians and non-solar technicians were responsible for these errors. This indicates that even if it is easy to get hold of a technician it is not that easy to get correct service.

Figure 7: A by-passed charge regulator.
(Photo from field study)

In some few cases preventative service had been performed. This had only happened when the installer was a solar company, and within guarantee time (first year).

Some people had replaced the old battery with a new one on their own and this had caused problems. It seems like an easy task, but there are some considerations that are important. For example, if the battery is disconnected from the charge controller and the charging panel is not, the charge controller will be overloaded. In most cases the fuse will blow, but if the fuse is replaced with metal thread there is a great risk that the charge controller will break. Also it is of great importance that the battery terminals are connected firmly to obtain minimum losses.

## Battery details

As mentioned before, all systems visited were installed 1996 or later, and a good part of these systems had not needed to change the battery at all, in fact more than half. As a consequence it is difficult to give detailed and statistically correct information on battery performance or average lifetimes on different types and brands of batteries. What can be observed is that of the systems installed in 1996 two thirds have changed the batteries once, and one fourth not at all. The average lifetime of the batteries installed in 1996 is over 3.5 years. All but one of these batteries were imported car batteries of an unknown brand. The reason they are of the same brand is that all these systems were installed by the same NGO.

The batteries that were or had been used in the solar electric systems encountered in this study were of four kinds: solar, modified auto, auto and truck batteries. Approximately one third of the batteries were of solar type, and the same goes for the modified car batteries. The remaining third was shared between ordinary car batteries and the bigger truck batteries.

A high proportion of the very recently installed systems is utilizing local UBL batteries, either the car batteries or the modified ones. In addition many households, which have changed batteries, have also chosen UBL for the new one. So it seems like UBL is improving its market position in solar applications. Already now about half of the batteries used were made by UBL. The leading brand for solar batteries was Chloride Exide, a Kenyan produced battery.

There are regional differences in types of batteries used. In Kibale car batteries or modified car batteries were dominating, while in Bushenyi and Rukungiri solar and modified ones were most common. In Mbale solar or truck batteries were mostly used. These regional differences are probably due to that there are different types of installers in these areas. In Kibale there is an NGO that has been very active in installing solar electric systems in 1996. And in both Bushenyi and Mbale some solar companies have branch offices.

## Fate of worn-out batteries and awareness

The awareness of possible environmental impact and health risks regarding the lead and sulphuric acid used in batteries was low. Few people knew that lead is used in batteries. In fact, most people did not know what lead is and consequently they did not know that it is unhealthy. People are a bit more concerned about the acid. Many know that it can eat its way through clothes and skin. It can be added though, that an adopted method when checking acid concentration in batteries is to dip a finger in the electrolyte and place a drop on the tongue. The more a drop stings, the higher concentration. Since the electrolyte in a lead-acid battery is diluted with lead compounds this is a serious matter.

Worn-out batteries are often considered as valuable property. And the majority of the replaced batteries were still in the homes, often next to the new one (see figure 8). In several cases the acid, diluted with lead compounds, had been poured out just outside the house. So far less then one tenth of the worn-out batteries had been transported to UBL in Kampala. The remaining batteries were either thrown outside or given to someone else, such as a friend, neighbour or employee.


Figure 8: Old batteries stored in households next to the operating battery. (Photos from field study)

## Comments from end-users

Most of the end-users were satisfied with the performance given by the solar electric system. Good quality light, information from radio and television and small operational expenses were often mentioned as benefits.

The most common complaint was the limited energy amount provided by the system. Most end-users wanted to extend their system, and actually almost one fifth of the households had added extra load such as extra lights or a bigger television, without extending the panel capacity. Many wanted to be able to use electricity for cooking and ironing. Other wanted improvements were; more end-user training, included spare parts, price reductions, and organized after-sale service.

## Inspection of battery location

Almost all battery locations were adequate in terms of being favorable for the battery lifetimes. That is shadowy, clean and relatively cool places. But in terms of health and security issues many locations were poor. Less than half of the batteries were put in lockable and empty rooms, or inside a wooden battery box. The majority were not in battery boxes and placed in widely used rooms (bedrooms, living rooms or dining rooms), exposed to children and animals. In some households where the battery had been replaced, the new battery was on top of a too small battery box that had been constructed for the old battery.


Figure 9: Examples of poor battery locations. Two batteries are placed on top of a too small battery box (left and middle). One is in a kitchen (middle), and the other two in bedrooms (left and right). (Photos from field study)

## Needed service and battery condition

The check of the battery condition is the most important component in the household survey. Technical problems, negligence, and mistakes made by technicians and end-users were revealed immediately. In the previous sections no exact figures have been specified, since some of the answers might have been subjective or vague. Therefore only rough amounts have been outlined. In this section, though, the percentage is specified, partly to emphasize the importance of this section and partly as a result of the reliability of the findings. The information on needed service and maintenance on the system has been summarized in table 2, and more detailed information on the battery condition is outlined in table 3.

More then half of the systems needed service or maintenance urgently (54%), and more than two thirds of these problems were somehow battery related (39%). Some of the problems (20%) were uncomplicated and could easily be prevented by proper end-user maintenance; for example topping up and simple improvements of battery connections. But many problems (15+12+7 = 34%) required service from a solar technician. About one third of these (12%) needed relatively cheap service such as improved battery terminals or new fuses. The rest (22%) needed to have costly items replaced, like the battery or the charge controller. (See table 2)

The problems that resulted in a non-functioning or poorly functioning system could in almost all cases have been prevented or delayed by proper maintenance or service. There is a great risk that problems requiring cheap measures to be taken can turn into a problem that is expensive to repair.

**Table 2: Status of the system, extent of battery related problems and needed repairs**

| System status | Sub total % | Battery problems % | Needed repairs | |
|---|---|---|---|---|
| | | | Cheap % | Costly % |
| Non-functioning (need technician) | 15 | 5 | 5 | 10 |
| Functioning poorly (need technician) | 12 | 7 | - | 12 |
| Need maintenance by technician | 7 | 7 | 7 | - |
| Need maintenance by end-user | 20 | 20 | 20 | - |
| **Total** | 54 | 39 | 32 | 22 |

More than one fourth of the systems had a too low electrolyte level and more than one fifth of the connections were in poor shape. In addition only 44% of the batteries had satisfactory acid concentrations. (See table 3)

The electrolyte level and the connections are relatively easy to correct and are very important for the efficiency of the system. The specific gravity is harder to adjust once it has become bad. To prevent this the system should not be overused and the acid concentration in the initial electrolyte should be carefully verified. If problems arise anyway, moderate overcharging might be one way to equalize the concentration. This is easy to do, but hard to explain to the end-user. There is a great risk that he/she will tamper with the system and cause worse problems. Some charge controllers perform equalization charges automatically.

**Table 3: Battery condition**

| | State | | |
|---|---|---|---|
| **Constituent** | **Good %** | **Do not know %** | **Bad %** |
| Connections | 64 | 15 | 21 |
| Specific gravity | 56 | - | 44 |
| **Constituent** | **Good %** | **Overtopped %** | **Low %** |
| Electrolyte level | 45 | 29 | 26 |

## 5.3 Interviews with solar companies

When the field study in the rural areas was completed it was apparent that another point of view was needed as well. As a result the interviews with the solar companies were carried through and revealed new problems and different aspects of already known problems.

### Approach and methodology

The number of solar companies in Uganda has increased radically within the last few years and it is difficult to predict the turnout of the supplying market. However seven relatively established and/or influential companies were identified for the interviews:

- Incafex Solar Systems
- Solar Energy For Africa
- Boomer Systems Ltd
- Energy Systems Ltd
- Magric Ltd
- UltraTec
- Solar Energy Uganda Ltd

A *survey form for solar companies* was compiled (see Appendix C) dealing with issues like marketing information, common customers, end-user training, personnel details, installing procedures, maintenance activities, battery details, problems, concerns and recycling. The survey form was mainly used as a guideline for what questions to ask. As with the end-user interviews, the author both asked and filled in the answers. Written material, like marketing brochures and end-user manuals, was also collected. It was a great advantage that the household interviews preceded those with the solar companies, since actual problems already were known.

People from URDT (installing NGO) and UREA (the umbrella organization for the companies) were interviewed. Since these organizations are very much involved with the companies, some of the material collected is utilized in the following section about the findings.

## Findings

Most companies offer 2-3 different battery brands for solar home systems, all of them have UBL as a cheap alternative. Common solar batteries were Chloride Exide, Varta and DETA. Apart from these brands there were about another ten different brands, which all only were supplied by a single company. Since the solar market is not yet very developed, relatively few of these batteries were purchased and imported, and consequently the cost per battery is very high. In addition the import taxes are high (48%).

Common opinions about UBL batteries were that they used to be unreliable in solar applications, but that improvements had been made lately. Regarding imported solar batteries main concerns were high prices and high import taxes.

Many of the problems the companies had experienced regarding batteries used in solar electric systems were related to misuse due to end-users' ignorance, such as the use of non-distilled water for topping up, non-solar technicians tampering with terminals or charging and extra load added. Still most of the companies only provided oral end-user training. Some of them provided written instructions, but then in English and often unnecessarily long and complicated.

For small solar home systems there was almost no organized preventative after-sale service. The general opinion was that this would be too expensive to realize, due to high transportation costs and scattered systems. Some companies stated that they had tried and failed, and one company phoned their customers (relatively big systems) twice a year. For very big customers (institutions or likewise) there was a possibility to have a service contract, e.g. someone came around every 6 months or so to check on the system and the batteries.

Neither of the companies carried out any sort of recycling. Old batteries were left behind at the households. Nor did any company provide the customers with information on health and environmental risks about the batteries.

The technicians' education level was often a certificate or diploma in electricity, combined with additional training in solar power or learn on job. There are relatively few solar technicians in Uganda and much of the personnel and resources are spent on back-up systems for households in Kampala. The general opinion about the market potential for solar electricity in rural areas is that it is good in terms of people desiring it, but low in terms of people being able to afford it. This is also reflected in the fact that most companies have none or few branch offices in the rural areas.

## *5.4 Other interviews*

There are a lot of influential stakeholders besides the domestic end-users and the solar companies in the PV market (see section 4.2). Some of these were included in the study to enable an overview of the market situation and forces acting in it.

### Approach and methodology

Information was obtained from interviews and/or study visits. The interviews were open and notes were taken. The following stakeholders were included:

- Uganda Batteries Ltd (UBL)
- Uganda National Bureau of Standards (UNBS)
- Uganda Photovoltaic Pilot Project for Rural Electrification (UPPPRE)
- National Environment Management Authority (NEMA)
- Battery charging stations
- Two Secondary Schools
- One Hospital
- Forum (NGO)
- Uganda Renewable Energy Association (UREA)

As mentioned before, also people from URDT were interviewed, but this material is included in the findings from the solar company interviews.

### Findings

The *quality* aspect is very important when trying to facilitate the introduction of solar power in Uganda. Attempts to secure good quality are the *Code of Practice for Installation of Photovoltaic Systems* that UNBS has set up, and the standards for batteries used in PV systems that is in progress. The existing standards are comprehensive and their legal status compulsory. But it is unclear how the enforcement is supposed to be effected. The solar companies and UREA certainly have an interest in good quality, since one major marketing channel is word of mouth. UREA can exclude members if they misbehave, even if detachment not possibly can be guaranteed. UBL are ISO 9000 certified, and the battery standards being set up by UNBS will hopefully result in batteries more suitable for PV applications.

The issue of *recycling* is complicated. The legislation regarding hazardous waste (NEMAs arrangement of regulations) appears very appropriate, but the enforcement is still in its infancy and there are huge problems to overcome before compliance is obtained. Amongst the shortcomings is lack of awareness and funding, not to mention lack of proper disposal and storage facilities. UBL is recycling some scrap batteries to use the lead in the production. But they only accept and recycle the amount of lead they require. No advertising or active collecting of worn-out batteries is needed; they get enough batteries anyway. Sometimes they even have to introduce restrictions (for example only accepting batteries on Thursdays) to moderate the inflow of old batteries. The compensation for worn-out batteries is 185 USh/kg batteries of which the electrolyte has been poured out and 230 USh/kg for just the plates after the case has been removed (Sendagala 2001). This is equivalent to 0.11 and 0.13 USD respectively. A very rough estimation gives that nearly 280 tons of lead from scrap batteries is currently accumulating each year in Uganda, just from UBL's production (see Appendix D for calculation). In addition a considerable number of batteries are imported/smuggled into Uganda each year. Forum (NGO) has looked into the feasibility of recycling and collecting remaining lead-acid batteries, and states that it would be relatively easy to collect them, if there were proper recycling facilities available. There are plenty of small battery charging stations around the country, where many worn-out batteries eventually end-up. Today batteries are recovered on a small scale where these are utilized as a base for the collecting.


Figure 10: Recycling at UBL. Batteries are dismantled as showed in the picture, then the lead plates are melted, and formed into new plates. (Photo from field study)

The objective of UPPPRE was to facilitate commercially based *dissemination* of PV, and this strategy has turned out to be very slow. There is still a long way to go before PV is a common electricity source in rural areas. Another way to disseminate PV is through donor-based projects providing solar to public institutions, in that way also ordinary people can enjoy PV electricity. The hospital and schools visited had benefited a great deal from their solar electric systems. But lack of maintenance and competent technicians was a major setback and a lot of improvements are needed in that field.

# 6 Evaluation of Survey

This chapter evaluates the findings from the field studies. The importance of the installing companies is discussed, together with the quality aspect of the locally produced batteries and the recycling issue. On the whole solar electricity has a great potential in Uganda, but there is scope for practical improvements on value of low cost, like for example improved end-user training. There is also need to take some radical measures, like organize recycling and monitoring of the solar companies.

## *6.1 The responsibility of the companies*

The installing companies and NGOs are the ones getting in contact with the end-users. Besides installing the solar electric systems they are the ones conducting end-user training, performing service and providing technical information. Hence they play a very important part in the viability of rural electrification based on PV. In this section the areas of responsibility of the companies are discussed and evaluated.

### End-user training

The end-user is a key person. He/she must be considered to be part of the system, since he/she is paying, operating and maintaining it. As a consequence the end-user training is a very important component in the installation process, and plenty of time should be spent on it.

As mentioned before, the end-user training in the visited households was mostly oral, given once, and to one person (mostly the husband) in the household. Clearly this is not sufficient, since less then one third of the interviewed end-users could list needed maintenance activities. This was confirmed by the fact that one fifth of the systems needed immediate end-user maintenance, and that a majority of the more severe problems could have been prevented or delayed, if proper maintenance had been carried out in the first place.

There are a lot of things an end-user is introduced to when the system is installed: for example how to operate the system, maintenance activities and safety issues. If all this information is given at once and only to one person it is easy to realize that some instructions are forgotten or misunderstood. If written instructions were provided the end-user could double-check the information. Most of the few manuals encountered in this study were very detailed and long, and in addition all were in English. This is acting as a deterrent when it comes to reading them. If the piece is very short, it might contain too little information though. One way to overcome these barriers is to provide two manuals; one partly graphic manual that is simple and short and can be pasted on the wall next to the battery to act as a reminder of maintenance (see example in Appendix E), and one more detailed handbook that explains instructions and functions of system components more carefully. A way to prevent misunderstandings regarding what to top up with is to provide a bottle of distilled water when installing. The bottle could also be labeled with instructions saying how and how often the topping up should be done. Furthermore it is important to train more than one person in the household. There were several examples in the field studies when the instructed person was not around often enough to take care of maintenance activities. In a majority of the households the woman is present most of the time and should for that reason be trained.

Another important aspect when it comes to end-user training is the instructing technician. He/she needs to realize how important the end-user training is, and needs to know exactly what the end-user needs to learn. A checklist could facilitate this. Furthermore emphasis should be put on the component of end-user training, when the technicians are trained in the first place.

## Marketing, environmental information and health concerns

Solar technicians had told some end-users that their systems relatively easy could be extended to run cooking facilities and ironing. This kind of false marketing is devastating for the PV market in the long run, since clients become very disappointed and word of mouth is a very important marketing channel. It is important to inform potential end-users both about advantages and limitations of solar electricity.

None of the companies informed the end-users about environmental risks and health concerns regarding lead and sulphuric acid. This is of course unacceptable and unfortunately a common phenomenon in developing countries where preventative work is neglected in favour of other more urgent problems. Besides, if the end-users are informed about health concerns involved with lead-acid batteries, the resulting question is:

-Where should old batteries be taken?

And this question does not have an answer. What can be said though is that batteries should be kept intact, the acid should not be poured out, old batteries should not be disposed outside, and children should not get to play with them. In addition well-vented battery boxes should always be provided to prevent electrical shock, short-circuited terminals, and to protect people in case of an explosion. The box should also be large enough to fit a bigger battery in the future.

## After-sale service

There are two kinds of after-sale service: preventative and actual repair work. They are of course very much related to each other, but one major difference is the end-users awareness. If a system is not functioning the end-user knows this very well and can contact a technician to carry out repair work. This is not necessary the case with a poorly functioning system.

The field study revealed that a third of the systems needed attendance by a solar technician. A majority of these systems were still functioning, but needed improvements not to break down too early or to cause unnecessary ageing of the battery. Most of the end-users were not aware that there was a problem, so the only way to come to terms with this is to organize some sort of preventive after-sale service.

Preventive service had been performed in some few cases. But this only happened when the installer was a solar company, and within guarantee time (first year). Apart from that there was no organized after-sale service for ordinary solar home systems. This is probably in consequence of the relatively high investment costs and the low operational expenses associated with solar electricity. The companies are spending almost all their technical and personnel resources on installations, since that is how they earn most of their money. And as a result the after-sale service is neglected. This is reinforced by the fact that transportation costs are high and systems are scattered in the rural areas.

There are a number of ways to organize after-sale service. One is to draw up a service contract. For example the end-user can pay a certain amount every year, and the solar company checks on the system 2-3 times a year. Another way is that the installer is the owner of the system and the actual end-users pay on a monthly basis. Then the company would have an economical interest in maintaining and servicing the system. A drawback with this option is that it might reduce the end-users sense of responsibility. A third way would be to carry out preventive service on all systems, which are near a system that has to be repaired. This requires very detailed documentation though. There is need for further studies in this area, to find out different approaches and alternatives.

Apart from lack of preventive service there were also shortcomings in the actual repair work. Even though it seemed relatively easy to get hold of a technician there were many mistakes that had been done, and both trained solar technicians and non-solar technicians were responsible for these errors. To solve this it must be easier for the end-users to contact skilled and reliable solar technicians. This requires more training for solar technicians combined with some sort of certificate or license to ensure quality service. In addition more branch offices and/or community based solar technicians would reduce contact difficulties.

## Branch offices

A great number of branch offices or community based solar technicians have many advantages. It would facilitate the after-sale service, the supply of spare parts, marketing activities and increase the awareness of solar electricity. This is only viable though, if the density of solar electric systems is relatively high, or if the technicians are combining solar with other work. One way to easily get a well-developed network is to utilize already existing once, like for example petrol stations. There the mechanics are often skilled technicians that with some training in solar power could install and repair solar electric systems.

## Enforcement of standards and monitoring of the companies

The preceding sections are establishing the great responsibility that the installing companies have. Unfortunately some shortcomings were revealed in the field studies and measures need to be taken to somehow secure the quality of their work. If a solar electrification program will be launched in rural Uganda it would be valuable to invest in some sort of monitoring work.

UREA has an important role in the solar electricity market. This association could put pressure on misbehaving companies, issue certificates for technicians and provide solar training to ensure solar a good reputation. But one must not forget that UREA is actually representing the companies, and it is not an independent authority.

The standards that UNBS has compiled are good and they all have compulsory legal status. The problem is how to enforce them. Solar electric systems need to be controlled in the field, detected shortcomings should be followed up and result in some sort of economical penalty. Lack of funding and personnel is one major problem for the full implementation of this enforcement though.

### The personnel situation

There is clearly a lack of skilled solar technicians in Uganda already today. If PV is about to be launched on a large scale the shortage will be even worse. For that reason it is of major importance to train and educate both solar technicians and business people. There should be a minimum requirement on previous education and knowledge. For example technicians should have at least a Diploma in Electricity before taking part in any solar training.

## *6.2 Uganda Batteries Ltd*

Even if UBL recently has accomplished improvements on their batteries, there is still scope for further improvements. UNBS's coming battery standards will hopefully achieve this. UNBS has, as mentioned before, some electric laboratory facilities that could be utilized for future studies like a bench test of different battery brands and types.

The Ugandan market is today highly protected by import taxes, and as a consequence UBL has an advantage over other competing battery producers. This is very sound, since this is a way to strengthen the local economy. But, UBL is not producing any solar batteries and nevertheless foreign solar batteries are also burdened with high import taxes. As long as UBL is not producing solar batteries these taxes should be removed, to facilitate the PV dissemination. Even better, though, would be if UBL started to produce solar batteries, similar to the ones produced in Kenya (Chloride Exide).

## *6.3 Recycling*

The lead-acid batteries used in solar applications are a very small fraction of the total amount used. The car fleet is responsible for almost all the battery usage. Accordingly the batteries used in PV systems are causing little environmental degradation compared to the batteries used in cars. Only a very drastic extension of the solar electricity market could change this situation. However there is already a problem related to scrap batteries in Uganda, due to the car fleet. This calls for major improvements in the recycling of lead-acid batteries.

As mentioned before it is probably quite easy to organize some sort of collection scheme for old batteries. One could use battery charging stations and/or garages that are scattered all over the country as a base for this. The problem is that there is nowhere to put the batteries. UBL gets enough scrap batteries already and there are no other recycling facilities in Uganda. The battery producers in neighbouring countries also get what they need already. UBL can use secondary lead only for the negative plate. For the positive one pure lead is imported. If it were possible to improve the recycling process to the extent so also at least some of the positive plate could be made out of secondary lead, without compromising the quality, it would be a notable progress. Perhaps there is scope for cooperation with the Kenyan battery producers?

While waiting for an improved recycling it might be an idea to consider the construction of a proper storage facility for scrap batteries. So they can be stored in a safe place to prevent lead from contaminating the environment and cause health problems.

# 7 Conclusions and recommendations

This final chapter more or less summarizes chapter 6 and consists of nine short recommendations to improve the battery aspect in solar electric systems in rural Uganda and to reduce the environmental impact caused by these batteries. At the end of each recommendation the level of the investment required and possible implementing stakeholders are indicated.

**1. Improve the end-user training**
The end-users should *always* get written instructions as a complement to the oral training: one maintenance manual that is very short, uncomplicated and primarily graphic (see example in Appendix E) that can be pasted up next to the battery, and one handbook that is more detailed and explains instructions, functions of system components, environmental risks and health concerns. (Extremely low, Installing Company)

**2. Provide one bottle of distilled water and a battery box when installing**
The installer should provide one bottle of distilled water to would prevent mistakes regarding what liquid the end-user use for topping up and also act as a maintenance reminder. The installer should also provide a battery box to improve the safety aspect. The box should be well vented and be a bit too big to hold a somewhat bigger battery as well. (Very low, Installing Company)

**3. More solar training for technicians**
More solar training is needed, since there is lack of competent solar technicians. This matter is a prerequisite for an extension of the solar electricity. There should also be a minimum requirement of a diploma in electricity for the persons being trained. The instructor should emphasize the importance of end-user training in the installation process. (Moderate, UREA)

**4. Organize some sort of system for after-sale service**
Studies are needed to evaluate different ways of organizing after-sale service. Systems should be implement that ensures the companies' economical interest also after the installation process. (Moderate, University)

**5. Perform a bench test of batteries**
Different kinds and brands of batteries should be tested in field conditions to compare prices with lifetimes. UNBS have laboratory facilities where it could be suitable to conduct these tests. (Moderate, UNBS and University)

**6. Increase the number of branch offices and community based technicians**
Marketing activities, after-sale service and the supplying of spare parts would be facilitated by an increased network of skilled technicians in the rural areas. Investigate the possibility to use already established networks. (Moderate/high, Installing Company)

**7. Enforce UNBS's standards and monitor the companies**
It is *very important* to ensure solar technology a good reputation. Enforcement of standards and monitoring of the solar companies need to be effected to secure this. Issue a "solar certificate" for technicians and companies. (High, Financing Authority/UNBS)

**8. Remove import taxes on solar batteries or start to produce them locally**
If solar batteries become cheaper the dissemination of solar electricity is facilitated. This would be obtained if the import taxes were removed or if there was local production of solar batteries. (High, Government/UBL)

**9. Organize lead recycling**
To prevent environmental degradation a recycling system of worn-out lead-acid batteries should be developed, either by the local battery producer or by collaboration with battery producers in bordering countries. (High, Government/UBL)

Solar electricity offers a great opportunity for rural households in Uganda to become electrified independently of the electric grid and governmental decisions. The implementation of the technology in rural Uganda is suffering from teething troubles, which have been pointed out in this thesis. To minimize the input of both money and labour these problems should be solved *now*, while solar electricity still is in its infancy. Then the rural population can look forward to a brighter future.

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# Appendices

| | |
|---|---|
| Appendix A: | Survey form for households |
| Appendix B: | A compilation of the answers from the rural field study |
| Appendix C: | Survey form for solar companies |
| Appendix D: | The amount scrap lead accumulated in Uganda |
| Appendix E: | Graphic maintenance manual |

## *Appendix A*

## SURVEY FORM FOR HOUSEHOLDS **Form number:……..**

This survey form is a tool to obtain information for a research project on enhancing rural electrification. Ms. Annamaria Sandgren, a student at Lund University, Sweden, carries out the project. The objective of the project is to make use of experiences made by end-users to improve the battery aspect in PV-systems. The project title is Batteries used within PV-systems in rural Uganda. Dr. Mackay Okure, Faculty of Technology, Makerere University provides guidance.

We will appreciate your contribution to this project by filling in the form as completely as possible. All information will be handled strictly confidentially.

## Questions

**1** District of Uganda…………………………………………………………………...
**2** Name of village……………………………………………………………………...
**3** Date………………………………………………………………………………….
**4** ☐ Man ☐ Woman
**5** Education level of the interviewee…………………………………………………..
**6** Family structure

| Age | Number of persons |
|---|---|
| 0 - 6 | |
| 7 - 13 | |
| 14 - 19 | |
| 20 + | |

**7** When was the installation of the PV-system made? (Year, month)……..…………....…
**8** What is the capacity of the panels? (Wp).....……………………….……………………
**9** What are the main purposes of the PV-system?
☐ Lighting
☐ Radio
☐ TV B/W
☐ TV Colour
☐ Video
☐ Back-up
☐ Refrigeration
☐ Other, please specify………………………..…………………………………...
**10** Please list the items connected to the system **at time of installation**? (Number, kind)
…………………………………………………………..……..……………………
…………………………………………………………………..……..……………
…………………………………………………………...…….………………………
**11** Please list changes made on the items connected to the system?
..……………………………………………………………….……………………….
..……………………………………………………………………………...………
…………………………………………………………………….…………………...

**12** How many hours are the different items used per day in average?
.......................................................................................................................................
.......................................................................................................................................

**13** Financing details about the system

| System cost | Subsidy / Donation | Cash | Credit | Payments size, interval | Interest rate | Amount left to pay off |
|---|---|---|---|---|---|---|
| | | | | | | |

**14** What is the monthly income of the household? (USh)…...........………...…………..…

**15** Through where did you get the initial information about PV-systems?

☐ Company
☐ Project
☐ Hearsay
☐ Other, please specify………………………………………………...…………………..

**16** Was there any instructions/training when the system was installed?

☐ Yes, a lot ☐ Yes, some
☐ No (Continue to **22**)

**17** What kind of instructions/training was given?

☐ Oral ☐ Written ☐ Other, please specify………………..……………………………...

**18** List the instructions/training
.......................................................................................................................................
.......................................................................................................................................
.......................................................................................................................................
.......................................................................................................................................

**19** Did you receive any specific instructions/training on the batteries?

☐ No ☐ Yes, please specify..…...…………………………………………………….
…………..........................................................................................................................
…………..........................................................................................................................
…………..........................................................................................................................

**20** Who gave the training?

☐ The installing company
☐ An independent technician
☐ Other, please specify………………………………………………..……………...

**21** Who received the training? (Number of people, male/female, position, education etc.)
…………………………..……………………………………………………...…………...
…………………………..……………………………………………………...……………

**22** Was there any training later on?

☐ No ☐ Yes, specify when…..……………………………………………………

**23** Is there any regular arrangement with a technician to check the system?

☐ Yes ☐ No (Continue to **25**)

**24** If yes, by whom is service taken care of and how often? (Continue to **26**)

☐ The installing company ☐ Monthly
☐ A local technician ☐ Yearly
☐ A training center ☐ Other, specify…………..……………………….
☐ Other, please specify……………………………………..……………………...

**25** If no, do you think there often is need for a technician?

☐ Yes ☐ No

**26** Rate the ease with which you can get an independent technician

☐ Very easy
☐ Easy
☐ Difficult
☐ Very difficult

**27** Did the installing company give any guarantee?

☐ No ☐ Yes, how many months?……..………………………..………………..

**28** Details about failures

| | Panels | Charge controller | Lights | Battery | Other, specify ……………. |
|---|---|---|---|---|---|
| Number of times replaced | | | | | |
| Cost per item | | | | | |
| Number of times repaired | | | | | |
| Cost per item | | | | | |
| Call / wait for technician | | | | | |
| Waiting time | | | | | |
| Warranty | | | | | |
| Comment | | | | | |

**29** What is your over-all impression of the system?

☐ Excellent
☐ Very good
☐ Sufficient
☐ Bad
☐ Very bad

**30** Which are the components that cause problems? (List in order, worst first)

……………………………..……..……………………………………………………
……………………..…………………..………………………………………………

**31** How many batteries have been used in total?……………..……………..……...………

**32** How many times has the battery caused failures?………...…...…………………….…

**33** Details about the batteries

| No. | Period (months) | Cost (USh) | Kind* | Who did you buy it from?** | Producer |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |

* For example; Automotive, PV, Modified automotive, Sealed, Traction, Deep-cycle
** For example; Solar Center, Local Dealer, Installing Company

Comments:……………………………………………………………………………………….
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

**34** How often do you carry out certain maintenance activities on the battery?

Daily = D, Weekly = W, Monthly = M, Yearly = Y, Never = N, Do not know how =?

| | |
|---|---|
| D W M Y N ? | Check the status of the charge controller |
| D W M Y N ? | Check the level of the electrolyte |
| D W M Y N ? | Top up with distilled water |
| D W M Y N ? | Dust the top of the battery |
| D W M Y N ? | Paste the poles and the connectors with petroleum jelly |
| D W M Y N ? | Perform boost charging |
| D W M Y N ? | Charge the battery at a battery charging station |
| D W M Y N ? | Check the terminals |

**35** Have you ever...

| Yes | No | | No. |
|---|---|---|---|
| ☐ | ☐ | …topped up with mixed acid | ☐ |
| ☐ | ☐ | …topped up with ordinary water | ☐ |
| ☐ | ☐ | …had the electrolyte replaced | ☐ |
| ☐ | ☐ | …applied grease to the terminals | ☐ |
| ☐ | ☐ | …had your charging adjusted without proper meters or tools | ☐ |

**36** What is your over-all impression of the batteries?

☐ Excellent
☐ Very good
☐ Sufficient
☐ Bad
☐ Very bad

**37** What happens to worn out batteries?

☐ Handed to local technician
☐ Handed to installing company
☐ Handed to Uganda Battery Ltd
☐ Stored, specify where.............................................................................................
☐ Other, please specify………………………………………………………..……...

**38** Do/did you receive money for used batteries?

☐ No ☐ Yes, specify how much?……………………………..……………..

**39** Do you have any concerns regarding the lead used in batteries?
☐ No
☐ Yes, please specify..........................................................................................................
Knows lead is used in batteries? Yes No
Knows what lead is? Yes No
**40** Do you have any concerns regarding the acid used in batteries?
☐ No
☐ Yes, please
specify...................................................................................................
Knows acid is used in batteries? Yes No
Knows what acid is? Yes No
**41** List specific benefits
……………………………………..……………………………………….……
……………………………………………………………………….……..…
…………………………………………………………………..……………..…
**42** List specific complaints
……………...……………………………………………………………….……
……………………...………………………………………………….…………
………………………………...…………………………………….……………
**43** Any suggestions for improvements
……………………………………...………………………………………………
………………………………….………….....…………………………………
……………………………..………………………...……………………………

## **Inspection of the battery and the location** (For interviewer only)
Kind of battery:……………………………………………………………………..…
Ampere-hours: …………………………………………………………………..…
Producer:…..………………………………………………………………………..…
Description of location (shadow, clean, dry, kind of room, placement, box):
……………………………….……………………………………………….…
………………………………………………………………………………….
Battery status (charging, fully charged):……………………………………….. ………
Voltage (charge controller):…………………………………………………………..
Voltage (measured):…………………………………………………………………..
Outside temperature:………………………………………………………..………
Battery temperature:…………………………………………………………………..
Time of the day.............................................................................................…………......
Connections:.......................................................................................................................
Maintenance manual:.........................................................................................................

| | | | | | | |
|---|---|---|---|---|---|---|
| Acid concentration: | | | | | | |
| Level: | | | | | | |

Comments:..........................................................................................................................
…………………………………..…………………………………………..…
Performed service:..............................................................................................................

## *Appendix B: Table 1.1 Kibaale district*

| No. | About the interviewee | | | General information about the system | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Gender | Education | Family structure | Date of installation | Panel capacity | Purpose of system | Initial items connected | Present items connected | Average use per day |
| 1 | M, F | S3, none | 4/1/0/4 | 5/1996 | 22 | L/R | 2/1 | No changes | 4/12 |
| 2 | M | S3 | 1/0/0/2 | 5/1996 | 22 | L/R | 2/1 | No changes | 4/6 |
| 3 | M | S4 | 2/3/0/2 | 7/1996 | 22 | L/R | 3/1 | No changes | 4/1 |
| 4 | M | University | 2/0/0/4 | 10/1997 | 51x2 | L/R/TVC/PC | 6/1/0/0 | 6/1/1/1 | 5/16/2/1 |
| 5 | M | P4 | 3/0/0/3 | 7/1996 | 22 | L | 2 | No changes | 4 |
| 6 | M | P7 | 5/6/4/5 | 10/1996 | 51 | L/R | 4/1 | Bigger tubes | 4/4 |
| 7 | F | S4+Nursing | 0/3/2/4 | 8/1996 | 22 | L/R | 2/1 | No changes | 4/12 |
| 8 | M | S6 | 0/2/3/4 | 8/1996 | 22 | L | 2 | Bigger tubes | 4 |
| 9 | M | S2 | 0/0/2/2 | 7/1996 | 51 | L/R | 4/1 | No changes | 3/3 |
| 10 | M | P6 | 24/6/5/3 | 7/1996 | 22 | L | 2 | No changes | 1 |
| 11 | | | | | | | | | |
| 12 | | | | | | | | | |
| 13 | M | S4 | 4/2/2/0 | ?/1998 | 22 | L/R | 2/1 | Also TVBW connected directly | |
| 14 | M | S4 | 2/4/0/3 | 6/1996 | 51 | L/R/TVBW | 4/1/1 | 1 extra tube | 3/16/1 |
| 15 | M | P3 | 2/2/0/2 | 1/1997 | 32 | L/R | 2/1 | No changes | 4/10 |
| 16 | M | P7 | 2/4/0/2 | 3/2001 | 36 | L/R/TVBW | 4/2/1 | No changes | 4/4/3 |
| 17 | M | P7 | | 6/2001 | 36 | L/Organ/Loud speakers | 4/1/3 | No changes | 1/1/3 (per week) |
| 18 | M | S2 | 0/1/4/2 | 5/2001 | 36 | L/R/TVBW | 3/1/1 | No changes | 4/6/4 |
| 19 | F | S3+Nursing | 1/0/2/2 | 5/1996 | 51 | L/R | 4/1 | 2 extra tubes | 4/16 |

## *Appendix B: Table 1.2 Kibaale district*

| No. | Financing details | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Income** | **Total system cost** | **Donation/ Subsidy** | **Down payment** | **Credit** | **Payments, size and date** | **Interest rate** | **Amount left to pay off** |
| 1 | 50 000 | 350 000 | 0 | 150 000 | 200 000 | 100 000, 50 000, 50 000 (once a year) | 15%, included in total cost | 0 |
| 2 | 150 000 | 350 000 | 0 | 140 000 | 210 000 | 100 000, 110 000 | 15%, included in total cost | 0 |
| 3 | ? | 350 000 | 0 | 120 000 | 230 000 | Once a year, for three years | 15%, included in total cost | 0 |
| 4 | 1 000 000 | 1 400 000 | 0 | 500 000 | 900 000 | 200 000/month | 15%, included in total cost | 0 |
| | 20 000 | 1 000 000 | 0 | 1 000 000 | 0 | | | 0 |
| 5 | 100 000 | 350 000 | 0 | 175 000 | 175 000 | 145 000, 30 000 | 15%, included in total cost | 0 |
| 6 | 400 000 | 1 400 000 | 0 | 700 000 | 700 000 | 300 000, 220 000, 250 000 (including penalty) | 15%, included in total cost | 0 |
| 7 | 1 000 000 | 350 000 | 0 | 175 000 | 175 000 | 100 000, 175 000 | 15%, included in total cost | 0 |
| 8 | 500 000 | 350 000 | 0 | 120 000 | 230 000 | 10 000 x 13, 20 000 x 5 | 15%, included in total cost | 0 |
| 9 | 200 000 | 1 400 000 | 0 | 500 000 | 900 000 | 500 000, 250 000, 200 000, 40 000 (including | 15%, included in total cost | 0 |
| 10 | | | | | | | | |
| 11 | | | | | | | | |
| 12 | 30 000 | | | | | | | |
| 13 | 100 000 | | | | | | | |
| 14 | 100 000 | 1 400 000 | 0 | 500 000 | 900 000 | 210 000, 200 000, 50 000, 50 000, 100 000, 180 000, 200 000 (including penalty) | 15%, included in total cost | 0 |
| 15 | ? | 300 000 | 0 | 300 000 | 0 | | | 0 |
| 16 | | 1 300 000 | 0 | 1 300 000 | 0 | | 15%, included in total cost | 0 |
| 17 | 120 000 | 1 300 000 | 0 | 800 000 | 600 000 | Within 6 months from installation | 15%, included in total cost | 600 000 |
| 18 | 250 000 | 1 300 000 | 0 | 1 040 000 | 260 000 | Within 4 months from installation | 15%, included in total cost | 260 000 |
| 19 | | 1 400 000 | 0 | 500 000 | 900 000 | 200 000, 200 000, 200 000, 170 000, 130 000 | 15%, included in total cost | 0 |

## *Appendix B: Table 1.3 Kibaale district*

| No. | Information | | End-user training | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Initial information** | **Guar-antee** | **Training /Instruc-tions** | **Kinds of training/ instructions** | **Listed instructions*** | **Specific battery instructions** | **Respon-sible for training** | **Receiver of training** | **Training later on** | **Comments** |
| **1** | URDT | 12 | Some T | L/D | | No | URDT | 1 F | No | |
| **2** | URDT | ? | Some T | L/D | | ? | URDT | 1 M | No | Did not interview the trained one |
| **3** | URDT | No | Some T | L/D | | No | URDT | 1 M | No | |
| **4** | Hearsay | No | No | | | | | | | Bought system from Kampala |
| **5** | URDT-staff lives nearby | 12 | A lot T | L/D | | Clean the battery | URDT | 1 M | No | |
| **6** | Neighbour URDT-staff | 12 | Some T | L/D | | Petroleum jelly. Scrub corrosion. Not on floor. Check level. Change electrolyte | URDT | 1 M | No | |
| **7** | URDT | 12 | A lot T | L/D/W | | Check level | URDT | 1 F | Yes, 1998 | |
| **8** | URDT | 12 | No | | | | | | | |
| **9** | URDT | No | Some T | L/D | | Top up | URDT | 1 M | No | Did not know distilled water |
| **10** | URDT | 36 | Some T | L/D | | Clean the dust | URDT | 1 M | No | |
| **11** | | | | | | | | | | System broke, only repaired |
| **12** | | | | | | | | | | Did only inspection |
| **13** | URDT | No | Some T | L/D | | No | URDT | 1 M | No | System broke down 2000 |
| **14** | URDT | 12 | Some T | L/D | | No | URDT | 1 M | No | |
| **15** | Neighbour | No | No | | | | | | | Installed it himself |
| **16** | URDT | No | No | | | | | | | Had an old system too |
| **17** | URDT | 6 | One I | O | If CC shows low, call a technician | No | Installing technician | 1 M | No | |
| **18** | URDT | 6 | Some I | O | Do not mess with the battery. Clean the panel | Call a technician when the water goes low. Do not disconnect | Installing technician | 1 M, 1 F | No | |
| **19** | URDT | 12 | A lot T | L/D/W | | Check level every 2-3 months. Top up. | URDT | 1 M,1 F | Yes, 1996 | |

**** This question was only posed to 17 and 18***

## Appendix B: Table 1.4 Kibaale district

| No. | After-sale service | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Arrange-ment with technician | Who/how often | Often need for a technician | To get a technician | Replaced | Repaired | Call/ Wait/ Self | Waiting time | Comments | Impres-sion of system | Problem compo-nent |
| 1 | Yes | Never came | Yes | Easy | B/1/70 000 | | C | 1 week | | VG | |
| 2 | Yes | ?/Yearly | | Easy | B/1/70 000 | | C | 1 week | | VG | |
| 3 | No | | Yes | Easy | B/1/70 000 | | C | 1 day | | E | B |
| 4 | Yes | Independent tech/monthly | No | Difficult, few tech | B/2/450 000<br>L/5/4 000 | CC/1/30 000 | C for B&CC | 1 day | Have added an inverter for 30 000. A generator is charging 2h/day. | S | CC |
| 5 | Yes | Never came | Yes | Easy | B/1/65 000 | | S | | | VG | |
| 6 | No, used to have | | Yes | Difficult, far | B/1/80 000<br>L/4/30 000 | | C<br>C | 3 days<br>3 days | Changed to bigger tubes and added 2 more. | VG | |
| 7 | No | | Yes | Very difficult | B/1/60 000 | CC/1/0 | C for CC<br>S for B | Never came | Finally they bypassed the CC themselves. | S | CC |
| 8 | Yes, charging | ?/ 4 months | No | Easy | L/2/30 000 | | C | 1 day | Changed to bigger tubes. | VG | |
| 9 | No | | No | Easy | B/1/80 000<br>L/8/5 000 | | S<br>S | | Had put in metal thread for fuses. | VG | |
| 10 | No | | No | Difficult | | | | | | VG | |
| 11 | | | | | | | | | | | |
| 12 | | | | | | | | | | | |
| 13 | No | | Yes | Difficult | L/1/20 000 | CC/1/10 000 | C for CC&L | 1 day | A non-solar technician came and bypassed the CC and put in new switches. The system has been down for a year or two. | VG | Socket |
| 14 | No | | Yes | Easy | L/7/5 000<br>B/1/100 000 | | S<br>S | | The battery was broken. | VG | Tubes |
| 15 | No | | Yes | Difficult, expensive | B/2/65 000<br>L/3/5 000 | | S<br>S | | Had no charge controller. | VG | |
| 16 | No | | No | Very easy | | | | | Newly installed | S | |
| 17 | No | | ? | ? | | | | | Newly installed | S | |
| 18 | No | | Yes | Very easy | | | | | Newly installed | E | |
| 19 | No | | Yes | Difficult | B/1/100 000<br>B/1/140 000<br>L/6/5 000<br>CC/1/20 000 | CC/1/30 000 | C for all | 1-2 days | | VG | |

## *Appendix B: Table 1.5 Kibaale district*

| No. | Battery details | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Total no.** | **Period** | **Cost** | **Kind** | **Seller** | **Producer** | **Ah** | **Comments** |
| **1** | 2 | 36/24 | I/70 000 | Auto/Modified Auto | I/LD | ?/UBL | 60/65 | |
| **2** | 2 | 36/36 | I/36 000 | Auto/Modified Auto | I/LD | ?/UBL | 60/65 | |
| **3** | 2 | 48/12 | I/70 000 | Auto/Auto | I/Kampala | ?/UBL | 60/70 | |
| **4** | 4 | 36,36/15,13 | I,I/450 000, 450 000 | Semitractionary,Solar/Solar,Solar | I,I/ Incafex, Incafex | STECO,Mastervolt/ Mastervolt, Mastervolt | 105,105/110,110 | Has two batteries connected in parallel. |
| **5** | 2 | 58/2 | I/65 000 | Auto/Auto | I/Kampala | ?/OHAYO | 60/50 | |
| **6** | 2 | 48/6 | I/80 000 | ?/Truck | I/Kampala | ?/?(Chinese) | ?/120 | |
| **7** | 2 | 36/24 | I/60 000 | Auto/Auto | I/LD | ?/OHAYO | 60/50 | |
| **8** | 1 | 60 | I | Auto | I | ? | 60 | |
| **9** | 2 | 48/8 | I/80 000 | Modified Auto/Auto | I/LD | STECO/UBL | 105/70 | |
| **10** | 1 | 60 | I | Auto | I | ? | 60 | |
| **11** | | | | | | | | |
| **12** | | | | | | | | |
| **13** | 1 | 24 | I | Auto | I | ? | ? | Broken system due to bad wires. |
| **14** | 2 | 36/24 | I/100 000 | ?/Modified Auto | I/Kampala | ?/UBL | 100 | Present battery dead. |
| **15** | 3 | 12/12/18 | 65 000/65 000/65 000 | Auto/Auto/Modified Auto | LD/LD/LD | UBL/UBL/UBL | 45/45/50 | No charge controller. |
| **16** | 1 | 4 | I | Modified Auto | I | UBL | 100 | |
| **17** | 1 | 1 | I | Modified Auto | I | UBL | 100 | |
| **18** | 1 | 3 | I | Modified Auto | I | UBL | 100 | |
| **19** | 3 | 36/15/9 | I/100 000/140 000 | Modified Auto/ Modified Auto/Truck | I/LD/LD | STECO/UBL/INCOE | 105/100/120 | |

## *Appendix B: Table 1.6 Kibaale district*

| Maintenance on the battery | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Maintenance activities | | | | | | | | Do not... | | | | | |
| | CC | Level | Top up | Clean | Petro-leum jelly | Boost charge | Charg-ing station | Term-inals | Top up with acid | Top up with tap water | Replace electro-lyte | Applied grease | Adjusted charging improperly | Comments |
| **1** | N | N | N | D | N | N | N | N | No | No | No | No | No | |
| **2** | N | M | N | D | N | N | N | N | No | No | **Yes** | No | No | Replaced in no.1 when bad, did no good |
| **3** | D | M | M | M | N | N | Y | M | **Yes** | No | No | No | No | Topped with acid in no.1 two times |
| **4** | W | M | M | M | Y | **D** | N | Y | No | No | No | No | No | Hospital generator charges 2h/day |
| **5** | D | N | N | W | N | N | N | N | No | No | Yes | Yes | No | |
| **6** | W | M | M | W | W | N | N | W | No | No | **Yes** | No | No | Replaced in no.1 two times |
| **7** | D | M | Y | W | N | N | N | N | No | No | Yes | No | **Yes** | The charging regulation was bypassed |
| **8** | M | M | Y | W | N | Y | M | Y | No | No | No | No | No | |
| **9** | W | W | **N** | M | N | M | N | N | Yes | No | No | No | No | Did not know distilled water |
| **10** | W | M | Y | Y | Y | N | N | N | No | No | No | Yes | No | |
| **11** | | | | | | | | | | | | | | |
| **12** | | | | | | | | | | | | | | |
| **13** | D | M | M | W | N | N | W | Y | No | No | No | No | **Yes** | A non-solar technician caused short-circuit |
| **14** | M | Y | Y | Y | N | N | Y | N | **Yes** | No | **Yes** | No | Yes | Replaced and topped with acid two times |
| **15** | | M | Y | M | N | N | N | N | No | No | No | No | **Yes** | He did the installation himself, no cc |
| **16** | D | M | N | W | Y | N | N | Y | No | No | No | No | No | Recently installed |
| **17** | | | | | | | | | | | | | | Very recently installed |
| **18** | D | W | N | W | N | N | N | N | No | No | No | No | No | Recently installed |
| **19** | D | N | Y | M | N | N | Y | N | No | No | **Yes** | No | No | Battery no.2 was never topped up and went bad in 15 months, a non-solar technician advised electrolyte changing |

## *Appendix B: Table 1.7 Kibaale district*

| No. | Fate of worn-out batteries and awareness | | | | | |
|---|---|---|---|---|---|---|
| | **Battery impres-sion** | **Fate of used batteries** | **Received money** | **Lead concerns** | **Acid concerns** | **Comments** |
| **1** | S | Son took it | No | No/No/No | No/Yes/Yes | Was told not to open the battery due to acid |
| **2** | B | URDT got it | No | No/No/No | No/Yes/Yes | Puts acid on tongue to check strength |
| **3** | S | Took it to their shop | | No/No/No | No/No/No | |
| **4** | S | Stored in the garage | | No/Yes/Yes | No/No/No | Knows lead is poisonous, but not how to deal with it |
| **5** | VG | Still there | | No/No/Yes | Yes/Yes/Yes | 4 batteries piled up (PV+radio). Wonders if replacing the acid can damage the plates. |
| **6** | VG | Left it at charging station | No | No/No/No | No/Yes/Yes | "It is bad to touch...??" |
| **7** | S | Still there | | No/No/Yes | No/Yes/Yes | Knows acid is bad to touch |
| **8** | VG | | | No/No/No | No/No/Yes | Still have the initial battery and it was doing fine |
| **9** | E | Still there | | No/No/No | No/Yes/Yes | |
| **10** | S | | | No/No/No | No/Yes/Yes | Still have the initial battery |
| **11** | | | | | | |
| **12** | | | | | | |
| **13** | S | Disposal, or car | | No/No/No | No/Yes/Yes | The system was broken |
| **14** | S | Still there | | No/No/No | Yes/Yes/Yes | Knows it is unhealthy |
| **15** | ? | Took it to neighbor (BCS), who took it to Kampala | No | No/No/No | No/Yes/Yes | Since no CC, do not know the battery performance |
| **16** | ? | Disposal | | No/No/No | No/Yes/Yes | Recently installed. Disposed old systems battery. |
| **17** | ? | ? | | No/No/No | No/No/No | Recently installed. Had know idea about where to put an old battery (amused by the question). |
| **18** | S | ? | | No/No/No | No/Yes/Yes | Recently installed. Do not know where to put an old battery (laughing). |
| **19** | S,B | Still there, man took to Kampala | No | No/No/No | Yes/Yes/Yes | Knows acid is unhealthy |

## *Appendix B: Table 1.8 Kibaale district*

| No. | Comments from end-users | | |
|---|---|---|---|
| | **Benefits** | **Complaints** | **Suggestions for improvements** |
| **1** | Information on the radio. Can read in the evenings. No fumes. | No following up training. No regular monitoring. Few hours in rainy seasons. | Want to expand the system. |
| **2** | Radio. Kids can study in evenings. | One light flicks. | |
| **3** | Do not buy paraffin and candles. Clean walls. | | Want to expand the system. |
| **4** | Proper light for reading. | Technical skills are limited around. Limited usage. | Want to expand the system. |
| **5** | More costumers to minibar. | Maintenance routines are poor. | A good maintenance system. |
| **6** | Do not buy kerosene. Kids perform better in school. Extended chat hours. | | |
| **7** | Can write in the evenings. | Too little capacity. | A big battery box. Want to expand the system. |
| **8** | Enjoy the light | Not enough hours rainy days. | |
| **9** | Good light | No spares included. | Want to have a colour TV connected to the system. Spares could be included. |
| **10** | No need for fuel. Just a flick of switch and it is light. Children can read in the evenings. | | |
| **11** | | | |
| **12** | | | |
| **13** | The battery | No spares included. | Include spares. |
| **14** | Do not have to buy dry cells and fuel. Good reading light. | Expensive. New battery will not last for long. | Want to expand it (iron, fridge, colour TV). |
| **15** | No buying of fuel etc. Enjoys listen to the radio. | | Want to expand the system. |
| **16** | Good reading | | The frame should be more solid. |
| **17** | Good light | | Could be cheaper. |
| **18** | Do not buy fuel. Good reading for the kids. | | |
| **19** | Good light | The batteries | Spare parts. Want to know how to get the initial kind of battery. |

## *Appendix B: Table 1.9.1 Kibaale district*

| No. | Location | | Needed service and battery condition | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Room/ placement** | **Shadow/ clean/ dry/ box** | **Kind** | **Ah** | **Producer** | **Status** | **Voltage** | **Temp I/O** | **Time** | **Connec-tions** | **Man-ual** | **Acid concentration** | **Level** | **Comments** |
| **1** | Bedroom/ Chair | Y/Y/Y/N | MA | 65 | UBL | Normal | **11.44** | 26/26 | 14 | ? | No | 1.18, 1.18, 1.19, 1.18, 1.18, 1.20 | ? | The battery too big for the panel? |
| **2** | Bedroom/ Chair | Y/Y/Y/N | MA | 65 | UBL | Normal | 12.55 | 25/26 | 15 | ? | No | 1.20, 1.20, 1.20, 1.20, 1.19, 1.20 | ? | |
| **3** | Hall/ Loudspeaker/ Carton | Y/Y/Y/N | A | 70 | UBL | ? | **10.62** | 25/25 | 17 | ? | No | 1.28, 1.28, 1.28, **X**, 1.18, 1.28 | One empty | Battery was disconnected from CC, but not the charging. Battery taken to BCS. |
| **4** | In locked wardrobe | Y/Y/Y/N | Solar<br>Solar | 110<br>110 | Mastervolt<br>Mastervolt | Normal | 12.82, 12.83 | 24/25 | 10 | OK | No | 1.25, 1.24, 1.24, 1.24, 1.24, 1.24 | OK | The batteries have instructions about disposal attached. |
| **5** | Hall/Chair/ Carton | Y/N/Y/N | A | 50 | OHAYO | Normal | 12.27 | 23/23 | 12 | ? | No | 1.24, 1.24, 1.23, 1.24, 1.24, 1.23 | Overtopped | |
| **6** | Hall/Wooden plate (tilted) | Y/Y/Y/N | Truck | 120 | ?(Chinese) | Low | 12.31 | 22/23 | 13 | Bad | No | 1.22, 1.23, **1.14, 1.13, 1.12, 1.14** | OK | Battery was a bit tilted. Too big for the panels and loose connections. |
| **7** | Bedroom/ Chair/ Carton | Y/Y/Y/N | A | 50 | OHAYO | ? | 12.78 | 24/24 | 15 | ? | No | 1.24, 1.22, 1.23, 1.23, 1.22, 1.24 | Overtopped | The **CC was bypassed**, new wires were too thin. |
| **8** | Bedroom/ Wooden plate | Y/Y/Y/N | A | 60 | ? | Normal | 12.70 | 22 | 17 | ? | No | 1.22, 1.22, 1.22, 1.22, 1.22, 1.22 | OK | The initial battery. The tubes were changed from 8W to 18W, too big load? |
| **9** | Bedroom/ Chair | Y/N/Y/N | A | 70 | UBL | **Boost charging** | 13.28 | 25/28 | 15 | OK | No | **X, X, X, X, X, X** | Very low | Topped up with distilled water and switched to normal charging. |

## *Appendix B: Table 1.9.2 Kibaale district*

| No. | Location | | Needed service and battery condition | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Room/ placement** | **Shadow/ clean/ dry/ box** | **Kind** | **Ah** | **Producer** | **Status** | **Voltage** | **Temp I/O** | **Time** | **Connec-tions** | **Man-ual** | **Acid concentration** | **Level** | **Comments** |
| **10** | Bedroom/ Chair/ Plastic cover | Y/Y/Y/N | A | 60 | ? | Normal | 12.65 | 25/27 | 18 | OK | No | 1.24, 1.24, 1.22, 1.22, 1.21, 1.20 | OK | The initial battery. |
| **11** | Bedroom/ Chair | | | | | | | | | | | | | System broken for a week. **Loose connections**, we only reconnected. |
| **12** | Empty room/ Wooden platform | Y/N/Y/N | A | 100 | UBL | ? | 13,36 | 24/24 | 11 | Bad | ? | 1.23, 1.24, 1.23, **X**, 1.24, **X** | Low, two empty | Only did inspection here. The trained person is only there in weekends. Topped up. Measured voltage without directly, declined normally. |
| **13** | Bedroom/ Chair | Y/Y/Y/N | | | | | | | | | | | | The panels had not charged the system for almost two years, due to **short circuit**. Battery used as bedside table, cigarette and kerosene lamp on top. |
| **14** | Bedroom/ Chair | Y/Y/Y/N | MA | 100 | UBL | Empty | **10.80** | 24/26 | 15 | OK | No | 1.25, 1.27, 1.25, **0**, 1.25, 1.25 | OK | Only distilled water in one cell. BCS 2 weeks ago, dead since then. |
| **15** | Bedroom/ Cement shelf/Carton | Y/N/Y/N | MA | 50 | UBL | | 12.60 | 25/26 | 16 | Bad | No | **X**, 1.20, 1.20, 1.20, 1.20, **X** | Low, two empty | Topped up with distilled water. No CC. |
| **16** | Dining room/ Chair | Y/Y/Y/N | A | 100 | INCOE | Normal | 13.76 | 28/27 | 13 | OK | No | ? | OK | Recently installed. Never disconnected and measured battery |
| **17** | Empty room/ Chair | Y/Y/Y/N | MA | 100 | UBL | Normal | 13.15 | 25/26 | 12 | OK | No | 1.23, 1.23, 1.23, 1.25, 1.24, 1.25 | Overtopped | Recently installed. |
| **18** | Dining room/ Chair | Y/Y/Y/N | MA | 100 | UBL | Normal | 13.03 | 27/27 | 14 | OK | No | 1.21, 1.20, 1.20, 1.20, 1.20, 1.21 | Overtopped | Recently installed. |
| **19** | Dining room/ Wooden box | Y/Y/Y/N | Truck | 120 | INCOE | Normal | 13.20 | 25/? | 16 | OK | No | 1.28, 1.28, 1.28, 1.28, 1.28, 1.28 | Overtopped | The new, large battery was on top of the too small battery box. |

## *Appendix B: Table 2.1 Bushenyi and Rukungiri district*

| No. | About the interviewee | | | General information about the system | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Gender | Education | Family structure | Date of installation | Panel capacity | Purpose of system | Initial items connected | Present items connected | Average use per day |
| 20 | M | S5+Technics | 3/0/0/4 | 5/2000 | 50 | L/R/TVC | 6/1/1 | No changes | 6/16/3 |
| 21 | M | S4 | 0/0/0/1 | 6/2000 | 155 | L/R/TVC | 21/1/1 | No changes | 8/7/5 |
| 22 | F | S4+Teaching | 2/3/2/2 | 5/2000 | 50 | L/R/TVBW | 6/1/1 | One less light | 4/3/0.5 |
| 23 | M | S4 | 2/3/5/3 | 1/2001 | | L/R/TVBW/V | 6/2/1/1 | No changes | 3/2/1 |
| 24 | M | P4 | 1/3/3/2 | 9/1999 | 64 | L/TVBW | 6/1 | No changes | 5/0.5 |
| 25 | M | S6 | 0/0/0/2 | 7/1999 | 64 | L/TVBW | 6/1 | One less light | (3)3/3 |
| 26 | F | S6 | 0/5/3/2 | 2/1996 | 120 | L/TVC/V | 12/1/1 | Same, but just back-up since a year | Before 3/0.5/0.5. Now as back-up once a week |
| 27 | F | P6 | 1/2/1/2 | 9/2000 | 32 | L/R | 7/1 | Added one light | 2/1 |
| 28 | F | S2 | 0/2/2/3 | 5/2001 | 60 | L/R/TVBW | 6/1/1 | No changes | 3/6/3 |
| 29 | F | P7 | 0/2/2/4 | 12/2000 | 135 | L/TVBW | 9/1 | Added two AC-lights á 40 W. | 4/3 |
| 30 | M | P4 | 5/2/2/5 | 4/1999 | 80 | L/R/TVBW/V/RF | 4/1/1/1/1 | No changes | 5/12/5/0.1/? |
| 31 | F | P7 | 2/2/1/3 | ?/1998 | 60 | L/R/TVC | 8/1/1 | No changes | 2/0.5/0.5 |
| 32 | M | S6 | 0/0/1/3 | 5/1999 | 192 | L/R/RF | 16/1/1 | Refrigerator broke down | (4)12/(3)4/2 |
| 33 | F | S4 | 2/3/0/3 | 8/1997 | 64 | L/R | 8/1 | No changes | 4/5 |
| 34 | F | P4 | 0/1/0/2 | 5/1997 | 75 | L | 8 | No changes | 7 |
| 35 | M | P6 | 0/0/0/7 | 12/2000 | 96 | L/R/TVBW | 6/1/1 | Added 2 lights | (3)3/3/2 |

## *Appendix B: Table 2.2 Bushenyi and Rukungiri district*

| No. | Financing details | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Income** | **Total system cost** | **Donation/ Subsidy** | **Down payment** | **Credit** | **Payments, size and date** | **Interest rate** | **Amount left to pay off** |
| **20** | 100 000 | 1500000 | | 1050000 | 450 000 | 100 000 per month | | 0 |
| **21** | 100 000 | 5247550 | | 2500000 | 2 747 550 | 1 373 775 in August and in October | | 0 |
| **22** | 200 000 | 1400000 | | 300000 | 1 100 000 | Cleared the credit within 9 months | | 0 |
| **23** | 100 000 | 1200000 | | 1200000 | 0 | | | 0 |
| **24** | 150 000 | 1050000 | | 1050000 | 0 | | | 0 |
| **25** | 80 000 | 989880 | | 494940 | 494 940 | Cleared the credit within 7 months | | 0 |
| **26** | 500 000 | 3600000 | | 2000000 | 1 600 000 | 800 000 after 6 and 12 months | | 0 |
| **27** | ? | ? | | ? | Yes | ? | | ? |
| **28** | 100 000 | 1900000 | | 900000 | 1 000 000 | 500 000 + 40 000 | | 460 000 |
| **29** | 200 000 | 1800000 | | ? | ? | ? | | 0 |
| **30** | 20 000 | 2000000 | | 2000000 | 0 | | | 0 |
| **31** | ? | 800000 | | 800000 | 0 | | | 0 |
| **32** | 400 000 | 4400000 | | 4400000 | 0 | | | 0 |
| **33** | 100 000 | 1850370 | | 1850370 | 0 | | | 0 |
| **34** | ? | | | | | Son bought the system for them | | |
| **35** | ? | 1070000 | | 550000 | 520 000 | | | 520 000 |

## *Appendix B: Table 2.3 Bushenyi and Rukungiri district*

| No. | Information | | End-user training | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Initial information** | **Guar-antee** | **Training /Instruc-tions** | **Kinds of training/ instructions** | **Listed instructions** | **Specific battery instructions** | **Respon-sible for training** | **Receiver of training** | **Training later on** | **Comments** |
| **20** | Friend | 12 | Some I | O/W | If problem contact company. | Top up with distilled water. | I | 1 M | No | |
| **21** | Solar Comp. | 12 | A lot | O/W | Don't touch! Call! | Put on grease. Clean the top. | I | 1 M | No | A good written piece. |
| **22** | Relative was at UPPPRE-seminar | Yes | Some I | W | Don't remember | Don't disconnect. Remove dust from top. | I | | No | Husband and wife not there when system installed. Complicated manual |
| **23** | Solar Comp. | 12 | One I | O | If problem contact company. | No | I | 1 M | No | Battery seller told to top up with diluted acid. |
| **24** | SEFCOA | No | Some I | O/W | Clean the panel. Check CC, red bad, green good. | Showed levels and told about topping up. | I | 1 M | No | Never read the written piece. The piece was good. |
| **25** | SEFCOA | 12 | Some I | O/W | Tell bishop or company if problem. | Top up with distilled water, NOT acid. | I | 1 M,1 F | No | |
| **26** | Friend | ? | ? | | | | | | | If training, husband got it. |
| **27** | ? | 12 | ? | O | Main switch off daytime. Don't use all lights at the same time. If green goes red, call technician. | ? | I | 1 M | No | Interviewed wife, husband was instructed. |
| **28** | Solar Comp. | 6 | Some I | O | If red, don't use all loads. | Check level, top up. | I | 1 M | No | |
| **29** | Neighbour solar tech. | 6 | Some I | O/W | Turn off main switch | No | I | 2 M,1 F | No | |
| **30** | Solar Comp. | 6 | No | | | | | | | Former UEB employee. |
| **31** | Friend solar technician | ? | A lot I | O | When cloudy don't worry, just wait. If problem call company. | No | I | All in family | No | |
| **32** | Radio, other users | 12 | Some I | O/W | Clean the panel. If want cooking add later on. | Check level. | I | 1 M | No | False marketing! |
| **33** | System nearby | 12 | Some I | O | Check CC. If problem, call technician. If want cooking add a battery later on. | Top up with distilled water. | I | 1M, 1 F | No | False marketing! |
| **34** | Son | ? | No | | | | | | | Husbund and wife new little. |
| **35** | DIOCESE | 12 | A lot I | O/W | | No metal or soap near battery. If well cared for can last 5 years | I | 1 M | No | He had already changed the electrolyte, just to try. |

## *Appendix B: Table 2.4 Bushenyi and Rukungiri district*

| No. | After-sale service | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Arrange-ment with technician** | **Who/how often** | **Often need for a technician** | **To get a technician** | **Replaced** | **Repaired** | **Call/ Wait/ Self** | **Waiting time** | **Comments** | **Impres-sion of system** | **Problem compo-nent** |
| **20** | Yes | I/3 months | | Very easy | L/1/5 000 | | C | 30 min. | | E | |
| **21** | Yes | I/2 months | | Easy | L/3/40 000 | | C | 1 day | | VG | |
| **22** | No | | Yes | Very difficult | | | | | One tube broken, still there. | S | Tubes |
| **23** | No | | No | Easy | L/6/? | | S | | A non-solar technician has done a great deal of the installation......badly. | S | MC-bulbs |
| **24** | No | | No | Difficult | L/1/35 000 | | S | | | VG | |
| **25** | No | | Yes | Very difficult | | | | | One tube broken, still there, doesn't use it anyway. | VG | |
| **26** | No | | No | Easy | L/2/30 000 | B/1/? | ? | ? | Solar technician did something with batteries. Bypassed CC. | S | |
| **27** | No | | No | Difficult | P/1/? L/Many/? B/1/0 | | ? | ? | Solar technician bypassed the cc, even though still within guarantee. That's why many tubes have been replaced. | VG | Battery |
| **28** | Yes | I/2-3 months | | Easy | | | | | | S | |
| **29** | No | | Yes | Difficult | L/3/3 000 | | ? | ? | Added panel and two lights. Part of system AC. One AC-bulb changed to a 100 W bulb. CC bypassed. | S | Inverter |
| **30** | No | | No | Very easy | L/5/5 000 | | S | | Former UEB employee. | VG | |
| **31** | Yes | Friend/often | | Easy | P/1/? L/2/? B/1/? I/1/? | | W | ? | Extended the system. | VG | |
| **32** | No | | Yes | Easy | L/4/5 000 | | S | | Had a small refrigerator that broke down within guarantee, never got it repaired. | S | |
| **33** | No | | No | Difficult | L/6/5 000 | | S | | | E | |
| **34** | Yes | I/Yearly | | Easy | L/6/5 000 CC/1/? B/1/? | | ? | ? | The system was struck by lightning and many things had to be changed. Son in Kampala paid and arranged with technician. | E | |
| **35** | No | | No | Easy | | | | | Added two lights, 40 000 each. | E | |

## Appendix B: Table 2.5 Bushenyi and Rukungiri district

| No. | Battery details | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Total no.** | **Period** | **Cost** | **Kind** | **Seller** | **Producer** | **Ah** | **Comments** |
| **20** | 1 | 14 | I | Modified Auto | I | UBL | 100 | |
| **21** | 4 | 13x4 | I | Modified Auto | I | UBL | 100 | 4 in parallel. |
| **22** | 1 | 14 | I | Solar | I | Chloride Exide | 67 | |
| **23** | 4 | 6x4 | 75 000x4 | Auto, Modified Auto x 3 | LD | UBL | 65 | Bought cheaper batteries himself. 4 in parallel. |
| **24** | 1 | 23 | I | Solar | I | Chloride Exide | 100 | |
| **25** | 1 | 25 | I | Solar | I | Chloride Exide | 100 | |
| **26** | 2 | 65x2 | I | Solar | I | Varta | 100 | 2 in parallel. Both are dead. Back up system. CC bypassed. |
| **27** | 2 | 4/7 | I/Guarantee | ?/Modified Auto | I/Solar company | ?/UBL | ?/100 | The CC was bypassed, probably broken. Should have been replaced. The first battery probably broken by CC. |
| **28** | 1 | 3 | I | Solar | I | Varta | 100 | Newly installed system. |
| **29** | 2 | 8x2 | I | Modified Auto | I | UBL | 100 | 2 in parallel. |
| **30** | 2 | 27x2 | I | Auto, Modified Auto | I | UBL | 100, | 2 of different sizes in parallel. One battery broken. |
| **31** | 3 | 36x2/1 | I/? | ?/Modified Auto | I/Solar friend | ?/UBL | ?/100 | The 2 initial were smaller than 100 Ah together. |
| **32** | 3 | 27x3 | I | Solar | I | DETA, 2 Autopower | 100 | 3 of two different brands in parallel. |
| **33** | 1 | 48 | I | Solar | I | Skanak | 115 | |
| **34** | 2 | 17/34 | I/? | ?/Modified Auto | I/? | ?/UBL | ?/100 | Lightning broke first one. |
| **35** | 1 | 8 | I | Solar | I | Chloride Exide | 100 | Had changed the electrolyte. |

## *Appendix B: Table 2.6 Bushenyi and Rukungiri district*

| Maintenance on the battery | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Maintenance activities | | | | | | | | Do not... | | | | | |
| | CC | Level | Top up | Clean | Petro-leum jelly | Boost charge | Charg-ing station | Term-inals | Top up with acid | Top up with tap water | Replace electro-lyte | Applied grease | Adjusted charging improperly | Comments |
| **20** | W | M | Y | W | M | ? | N | M | No | No | No | No | No | |
| **21** | D | W | Y | M | M | ? | N | M | No | No | No | No | No | Good written instructions. |
| **22** | D | ? | ? | N | ? | ? | N | ? | No | No | No | No | No | Complicated written instructions. |
| **23** | W | W | M | N | N | ? | N | N | No | No | Yes | No | **Yes** | Non-solar technician did most of the installation. Once the battery in the car stopped working, and he swapped that one with one in the system. |
| **24** | D | N | N | M | M | ? | N | N | No | No | No | No | No | Never read the instructions. |
| **25** | D | M | Y | Y | N | ? | N | N | No | No | No | Yes | No | |
| **26** | N | N | ? | N | N | ? | N | N | ? | ? | ? | ? | **Yes** | Solar technician bypassed the regulator. |
| **27** | D | Y | Y | D | N | ? | N | N | No | No | No | Yes | **Yes** | Solar technician bypassed the regulator. |
| **28** | W | ? | ? | N | ? | ? | ? | ? | No | No | No | No | No | Interviewed wife, husband got instructions. |
| **29** | D | N | ? | M | N | ? | ? | N | No | No | No | No | **Yes** | CC was bypassed. |
| **30** | D | M | Y | N | N | **M** | N | N | No | No | No | No | No | If yellow light, stop using load for 3 days. |
| **31** | D | N | N | W | N | ? | N | N | No | No | No | No | No | |
| **32** | W | M | Y | M | Y | ? | N | N | No | No | No | No | No | |
| **33** | N | Y | Y | N | N | ? | N | N | No | No | No | No | No | |
| **34** | D | M | N | W | N | ? | N | Y | No | No | No | No | No | |
| **35** | W | M | **?** | N | Y | ? | N | M | No | No | **Yes** | No | No | He thought one was supposed to change electrolyte, not top up. |

## *Appendix B: Table 2.7 Bushenyi and Rukungiri district*

| No. | Fate of worn-out batteries and awareness | | | | | |
|---|---|---|---|---|---|---|
| | **Battery impres-sion** | **Fate of used batteries** | **Received money** | **Lead concerns** | **Acid concerns** | **Comments** |
| **20** | S | Hand to installing comp.* | | No/No/No | No/Yes/Yes | |
| **21** | VG | Store, or dispose it in compost pit.* | | No/No/No | No/Yes/Yes | |
| **22** | S | Don't know* | | No/No/Yes | No/Yes/Yes | |
| **23** | S | Throw it out* | | No/No/No | No/Yes/Yes | "Throw them out, give my children to play with." |
| **24** | E | Throw it outside* | | No/No/No | Yes/Yes/Yes | Told in seminar batteries are bad for the environment. Knows acid can destroy clothes and burn the skin. |
| **25** | S | To battery seller* | | No/No/No | No/Yes/Yes | |
| **26** | S | To town* | | No/No/No | No/No/Yes | |
| **27** | S | To installing company | No | No/No/No | No/Yes/Yes | |
| **28** | S | Throw it away (laughter)* | | No/No/No | No/No/No | |
| **29** | S | Don't know (laughter)* | | No/No/No | Yes/Yes/Yes | Knows acid burns clothes and people. |
| **30** | E | Throw it outside* | | No/Yes/Yes | Yes/Yes/Yes | Knows that lead is poisonous, but he didn't have any concerns. Perhaps will melt and make soldering out of it. Knows you can't drink acid. |
| **31** | E | Solar friend took them | No | No/No/No | No/Yes/Yes | |
| **32** | VG | Throw them outside* | | No/No/No | No/Yes/Yes | He would throw old batteries outside, but not on his own property. |
| **33** | E | "Keep it in my house"* | | No/No/No | No/Yes/Yes | |
| **34** | E | Solar technician took it. | No | No/No/No | No/Yes/Yes | |
| **35** | ? | "It is my property now, they can't take it away from me"* | | No/No/No | Yes/Yes/Yes | Knows acid is poisonous and burn clothes. Still tests the strength with the finger. |

***The ones that still had the initial battery. I asked them where they thought they were going to put it once it gets old.***

## *Appendix B: Table 2.8 Bushenyi and Rukungiri district*

| No. | Comments from end-users | | |
|---|---|---|---|
| | **Benefits** | **Complaints** | **Suggestions for improvements** |
| **20** | Don't have to buy dry cells and paraffin. Now has a colour TV. | Not enough light hours in rainy seasons. Expensive. | Expand with refrigerator and iron. |
| **21** | Security | | |
| **22** | The system is reliable. | Lack of training. | Add fridge and cooking gears. |
| **23** | Lighting | | Change the MC-bulbs. |
| **24** | Easy light, convenient and clean. | | Stronger, to cook and iron. |
| **25** | Don't have to store paraffin. | | Expand to enable cooking. |
| **26** | Light | Not enough light hours. | |
| **27** | Light | | Bigger panel and battery |
| **28** | Good to have light, radio and TV. | | Fridge and iron. |
| **29** | Good to have light and TV. | When cloudy no light hours. Not reliable, only 2 lights. | Connect the radio to the system. |
| **30** | TV | | Solar training so he can help his neighbours. |
| **31** | Don't have to look for paraffin when visitors come. | | More training. |
| **32** | Lights, radio, security. | Limited use. The initial information. Confiscated his fridge and inverter. | |
| **33** | Enough light. Don't spend on paraffin and dry cells. | | Cook and TV. |
| **34** | Good light, don't buy kerosene. | | Add TV |
| **35** | Don't worry about paraffin when visitors. Information and entertainment through TV. Villagers come to watch. | | Improve capacity for cooking and ironing (informed it wasn't possible). Wants marketing compensation. Want written battery instructions. |

## Appendix B: Table 2.9.1 Bushenyi district

| No. | Location | | Needed service and battery condition | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Room/ placement** | **Shadow/ clean/ dry/ box** | **Kind** | **Ah** | **Producer** | **Status** | **Voltage** | **Temp I/O** | **Time** | **Connec-tions** | **Man-ual** | **Acid concentration** | **Level** | **Comments** |
| **20** | Bed room/ On wooden | Y/Y/Y/N | MA | 100 | UBL | Normal | 12.81 | 22/24 | 10 | OK | C, T, D | ? Hydrometer was broken | All over-topped | Hard to tell status without hydrometer. |
| **21** | Empty room/ | Y/N/Y/Y | MA x 4 | 100 | UBL | Normal | 12.31 (parallel) | 23/23 | 11 | OK | C, T, D | ? Hydrometer was broken | All OK | Hard to tell status without hydrometer. |
| **22** | Hall/ Wooden | Y/N/Y/N | Solar | 67 | Chloride Exide | Normal | 12.71 | 26/27 | 14 | OK | No | **X**, 1.25, 1.25, **X**, 1.25, 1.25 | 2 low, 4 OK | Told to top up with distilled water and showed how to change tube. |
| **23** | Living room/ Big locker with a lot of electronics. | Y/N/Y/Y | MA<br>MA<br>MA<br>A | 65<br>65<br>65<br>65 | UBL<br>UBL<br>UBL<br>UBL | Normal | 13.15<br>12.88<br>12.80<br>13.09 | 26/? | 17 | **Very bad** | No | **X, >1.30, X, X, >1.30, >1.30**<br>1.22, 1.22, 1.22, 1.22, 1.22, 1.22,<br>1.22, 1.22, 1.20, 1.20, 1.22, 1.20<br>1.27, 1.30, 1.29, 1.27, 1.27, 1.27 | L, OK, L, L, OK, OK<br>All OK<br>All over-topped<br>All OK | He had bought the things himself and had a local, non-solar technician to do the installation. Bad wiring, thin wires, the batteries badly connected (swapped one battery with the one in the car). In same locker as CC and valuable electronics. |
| **24** | Living room/ Wooden | Y/N/Y/N | Solar | 100 | Chloride Exide | Normal | 12.67 | 22/25 | 10 | OK | No | **X, X, X, X, X, X** | Very low | Told about topping up and do something about the tilting. |
| **25** | Dining room/ On wooden box | Y/Y/Y/N | Solar | 100 | Chloride Exide | Normal | 12.76 | 24/24 | 12 | OK | No | 1.25, 1.27, 1.25, 1.27, 1.25, 1.27 | All OK | A bottle of distilled water next to the battery. |
| **26** | Empty room/ | Y/Y/Y/Y | Solar x 2 | 100 | Varta | Normal | 12.77 (parallel) | 25/27 | 15 | Grease | No | **1.10**, 1.28, 1.27, 1.27, 1.23, 1.27<br>1.25, 1.25, 1.26, **1.15**, ?, 1.25 | All OK | A month ago a solar technician was did something with the batteries. Probably topped up, greased and **bypassed the CC.** |
| **27** | Bed room/ Wooden | Y/Y/Y/Y | MA | 100 | UBL | Empty | **10.12** | 26/27 | 16 | Grease | C, T, D | **0, 0**, 1.18, 1.18, 1.13, 1.18 | All over-topped | **CC bypassed** by solar technician. Changed tubes very often. |

## *Appendix B: Table 2.9.2 Rukungiri district*

| No. | Location | | Needed service and battery condition | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Room/placement** | **Shadow/ clean/ dry/ box** | **Kind** | **Ah** | **Producer** | **Status** | **Voltage** | **Temp I/O** | **Time** | **Connec-tions** | **Man-ual** | **Acid concentration** | **Level** | **Comments** |
| **28** | Living room/ Wooden stand | Y/Y/Y/Y | Solar | 100 | Varta | Normal | 12.70 | 24 | 10 | OK | C, D, T | 1.23, 1.23, 1.23, 1.23, 1.25, 1.23 | All OK | A newly installed system. |
| **29** | Bed room/ Wooden | Y/Y/Y/Y | MA x 2 | 100 | UBL | ? | 12.24<br>12.40 | 24/25 | 11 | Loose | D, T | 1.16, 1.16, 1.15, 1.17, 1.15, 1.13<br>1.15 x 3, 1.16, 1.16, 1.17 | All over-topped | **CC was bypassed.** They were complaining about light hours. Part of the system was AC. One bulb 100 W! |
| **30** | Bed room/ | Y/N/Y/N | MA A | 100 | UBL | Normal | 12.90<br>12.66 | 24/24 | 16 | OK | No | 1.28 x 6<br>1.28 x 5, **1.00** | All OK | One cell is dead, should simply remove that battery. |
| **31** | Living room/ | Y/N/Y/Y | MA | 100 | UBL | Normal | 12.52 | 25/? | 17 | OK | No | 1.20, 1.20, 1.20, 1.20, 1.18, 1.20 | All over-topped | A friend, who is solar technician, comes around often. |
| **32** | Empty room/ Wooden | Y/Y/Y/Y | Solar x 3 | 100 | DETA<br>Autopowe<br>Autopowe | Normal | 12.35 (parallel) | 24/24 | 12 | OK | No | **>1.30 x 6**<br>1.18 x 5, 1.20<br>1.18 x 2, 1.20 x 4 | All low<br>All OK<br>All low | Told him to top up. The low levels could cause the high concen-tration in one of the batteries. |
| **33** | Living room/ Wooden stand | Y/Y/Y/Y | Solar | 115 | SKANAK | Low | 12.41 | 21/21 | 10 | OK | No | 1.22, 1.22, **X**, **X**, 1.22, **X** | All low, two very low | Told them to top up, clean the panel and wait for two days. |
| **34** | Living room/ Wooden stand/ Carton | Y/Y/Y/Y | MA | 100 | UBL | ? | 12.58 | 22/23 | 11 | OK ? | No | 1.23, 1.23, 1.23, 1.23, 1.23, 1.23 | All OK | Connections beginning to corrode? Put on vaseline. Bad weather the day before. |
| **35** | Store room/ Wooden table/ Carton | Y/Y/Y/N | Solar | 100 | Chloride Exide | Normal | 12.74 | 26/26 | 17 | OK | No | **1.18**, 1.22, 1.23, 1.23, 1.23, 1.25 | All over-topped | He had changed the electrolyte. |

## *Appendix B: Table 3.1 Mbale district*

| No. | About the interviewee | | | General information about the system | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Gender** | **Education** | **Family structure** | **Date of installation** | **Panel capacity** | **Purpose of system** | **Initial items connected** | **Present items connected** | **Average use per day** |
| **36** | M, M | S3, S6 | 0/0/2/1 | 5/2000 | 170 | L/TVC*/M | 10/1/1 | No changes | 6/0.5/6 |
| **37** | W | S6+Public health | 0/2/2/9 | ?/1998 | 60 | L/R/TVBW | 5/1/1 | No changes yet, are about to add inverter and colour TV. | 6/12/4 |
| **38** | W | P7 | 1/0/2/2 | 5/1997 | 100 | L/R/TVBW | 4/1/1 | Added 3 lights | 3/16/1 |
| **39** | W | S4 | 1/2/1/3 | 2/1999 | 83 | L/R/M | 7/1/1 | No changes | 5/10/2 |
| **40** | W | S3+Teaching | 1/0/0/2 | 1/2000 | 60 | L/M | 3/1 | No changes | 5/1 |
| **41** | W | S4 | 2/1/3/5 | 1/2000 | 64 | L/R/TVBW/V | 6/1/2/1 | No changes | 3.5/3/0.75/0.5 |

***** The colour TV was very big and consumes a lot. There was also an inverter, even for the lights.***

## *Appendix B: Table 3.2 Mbale district*

| No. | Financing details | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Income** | **Total system cost** | **Donation/ Subsidy** | **Down payment** | **Credit** | **Payments, size and date** | **Interest rate** | **Amount left to pay off** |
| **36** | ? | ? | | 100% | 0 | | | 0 |
| **37** | 500 000 | ? | | 100% | 0 | | | 0 |
| **38** | 600 000 | 700 000 | | 700 000 | 0 | | | 0 |
| **39** | 170 000 | 1 800 000 | | 1 300 000 | 500 000 | 500 000 three months later | | 0 |
| **40** | ? | ? | | ? | ? | | | 0 |
| **41** | 100 000 | 1 600 000 | | 1 000 000 | 600 000 | 300 000, 100 000, 100 000, 30 000, 30 000, 20 000 | | 20 000 |

## *Appendix B: Table 3.3 Mbale district*

| No. | Information | | End-user training | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Initial information** | **Guar-antee** | **Training /Instruc-tions** | **Kinds of training/ instructions** | **Listed instructions** | **Specific battery instructions** | **Responsible for training** | **Receiver of training** | **Training later on** | **Comments** |
| **36** | Kampala | ? | Some I | O | Don't overload, No lights on when watching TV | No | I | 1 M | No | Uncle received the training and told his nephews which was interviewed |
| **37** | Cousin from Kenya | ? | Some I | O | | Clean the top, put on oil, add acid. | I | 1 M, 1 F | No | The parents received the training. The daughter was interviewed. |
| **38** | Radio and paper adverts + other PV-owners | No | Some I | O, W | | Change acid when the level is low | An independent technician installed. He was solar trained in Nairobi. | 1 M | No | The husband received the training. The wife was interviewed. |
| **39** | Radio advert + saw in Kasese | Yes | Some I | O | Clean the panel every 3 months. | Check the level, if low add distilled water. | I | 1 F | No | |
| **40** | Son | No | Some I | O | | Check the level, if low add distilled water. | Son | 1 M | No | Son bought and installed the system. Not a solar technician, but Electrical Engineer. Son trained nephew. |
| **41** | Radio advert | 12 | Some I | O, W | Clean the panel. | Check the level, if low add acid. | I | 1 F | No | An empty bottle of battery acid was next to the battery. |

## *Appendix B: Table 3.4 Mbale district*

| No. | After-sale service | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Arrange-ment with technician | Who/how often | Often need for a technician | To get a technician | Replaced/ Added | Repaired | Call/ Wait/ Self | Waiting time | Comments | Impres-sion of system | Problem compo-nent |
| **36** | No | | No | Easy | | W/1/? | C | 1 day | The wire from the panel was short-circuited | S | |
| **37** | No | | Yes | Easy | L/1/?<br>B/2/?<br>W/1/? | P/1/? | ? | ? | An independent technician made the initial installation. Then an Ugandan solar company remade the wiring, the mounting of the panels etc. | S | Battery and switching |
| **38** | No | | Yes | Difficult | P/1/?<br>B/2/?<br>L/7/? | | C<br>C,S<br>C,S | 1 day | Extended the system with one panel, one battery and three lights. Made by an independent solar technician. | VG | |
| **39** | No | | No | Easy | B/1/0 | | ? | ? | The first battery lasted 2-3 weeks, changed within guarantee time. 3 tubes blown but not changed. | S | Tubes |
| **40** | No | | Yes | Difficult | B/1/55 000 | | C | 1 day | One light broken but not changed. The system has not worked for a couple of months. | VG | |
| **41** | No | | Yes | Easy | L/4/5 000<br>F/1/2 500 | | S | | Contacted a technician that told them what to do and buy over the phone. | S | |

## *Appendix B: Table 3.5 Mbale district*

| No. | Battery details | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Total no.** | **Period** | **Cost** | **Kind** | **Seller** | **Producer** | **Ah** | **Comments** |
| **36** | 3 | 14x3 | I | 2 Submarine, 1 Solar | I | 2 Trojan Marine, 1 Chloride Exide | ? | 3 in parallel. |
| **37** | 3 | 12/24/1 | I/?/? | ?/Auto/Truck | I/?/Solar company | ?/Hi Dash/ OHAYO | ?/75/ 120 | |
| **38** | 3 | 24/24x2 | I/?/? | ?/ 2 Solar | I/? | ?/Voltmaster, Chloride Exide | ?/100x2 | Extended the system. Now 2 in parallel. |
| **39** | 2 | 1/30 | I/I | Truck/Truck | I/I | Exide/Exide | 120/120 | Changed the first battery within guarantee. |
| **40** | 2 | 18/4 | I/55 000 | ?/Auto | I/? | ?/UBL | ?/50 | The system has not worked since the battery was changed. |
| **41** | 1 | 19 | I | Truck | I | UBL | 120 | |

## *Appendix B: Table 3.6 Mbale district*

| No. | Maintenance on the battery | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Maintenance activities | | | | | | | | Do not... | | | | | |
| | CC | Level | Top up | Clean | Petro-leum jelly | Boost charge | Charg-ing station | Term-inals | Top up with acid | Top up with tap water | Replace electro-lyte | Applied grease | Adjusted charging improperl | Comments |
| **36** | D | N | ? | N | N | ? | N | N | No | No | No | No | No | |
| **37** | D | M | Y | W | Y | ? | Y | N | ? | No | ? | No | **Yes** | A non-solar technician did the installation. |
| **38** | D | W | **?** | W | N | ? | **M** | W | **?** | **?** | **?** | No | **Yes** | Have taken the battery to a garage about ten times. Are not sure what they did there. |
| **39** | D | M | Y | Y | Y | ? | N | N | No | No | No | No | No | |
| **40** | D | Y | Y | M | N | ? | Y | N | No | No | No | No | **Yes** | The son installed the system, and did it very well. |
| **41** | D | M | N | M | N | ? | N | N | **Yes** | No | No | No | No | An empty bottle battery acid next to the battery |

## *Appendix B: Table 3.7 Mbale district*

| No. | Fate of worn-out batteries and awareness | | | | | |
|---|---|---|---|---|---|---|
| | **Battery impres-sion** | **Fate of used batteries** | **Received money** | **Lead concerns** | **Acid concerns** | **Comments** |
| **36** | S | Throw it outside* | | No/Yes/Yes | Yes/Yes/Yes | Are afraid the acid can become weak. |
| **37** | S | Gave away/Stored | No | No/Yes/Yes | No/Yes/Yes | Gave the first battery to a worker. The second was still next to the new one. |
| **38** | B | To town | ? | No/No/Yes | Yes/Yes/Yes | Took the battery to town for reparation. Wouldn't drink the acid. |
| **39** | VG | To installing company | No | No/No/No | No/No/Yes | The technician who brought the new battery took the old one as well. |
| **40** | S | Next to the new one. | | No/No/No | No/No/Yes | |
| **41** | S | Stored | | No/No/No | No/Yes/Yes | Up side down outside, used as a chair. The acid was pored out. |

***Still had the initial battery. I asked them where they thought they were going to put it once it gets old.***

## *Appendix B: Table 3.8 Mbale district*

| No. | Comments from end-users | | |
|---|---|---|---|
| | **Benefits** | **Complaints** | **Suggestions for improvements** |
| **36** | Easy light. No power shadings. Bright. | Too weak. When the TV is used the number of light hours are too few. | Maybe increase the number of batteries. |
| **37** | No monthly costs. | Before it was bad, but now it is improved. | |
| **38** | Get energy from sunshine instead of using petrol. | Expensive. Limited. No sunshine-no light. | More education |
| **39** | Cheaper then getting the grid. No bills. No smoking lamps. | When a specific light is on there is a noise in the radio. | Periodical checking by technician. |
| **40** | Free from buying paraffin. | Limited, since no cooking. | |
| **41** | No monthly bills. No meter box. | Limited, want cooking and ironing. | Wants some panel protection from thieves. |

## *Appendix B: Table 3.9 Mbale district*

| No. | Location | | Needed service and battery condition | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Room/placement** | **Shadow/ clean/ dry/ box** | **Kind** | **Ah** | **Producer** | **Status** | **Voltage** | **Temp I/O** | **Time** | **Connec-tions** | **Man-ual** | **Acid concentration** | **Level** | **Comments** |
| **36** | Garage/In metal box mounted on the wall. | Y/N/Y/Y | Solar x 3 | ? | Trojan<br>Trojan<br>Chloride exide | ? | **11.33** (parallel) | 26/26 | 11 | OK | No | **All 0**<br>**Three 0, three ?**<br>**Three 0, three ?** | All OK<br>All OK<br>All OK | A bit tilted. The inverter was on top. Difficult to get to the batteries and measure. Tried the hydrometer on another battery to see if it was working. It did. |
| **37** | Empty room/ On wooden plate | Y/Y/Y/N | Truck | 120 | OHAYO | ? | 12.42 | 28/28 | 12 | OK | No | 1.18, 1.18, 1.20, 1.20, 1.20, 1.20 | All OK | Recently changed to a bigger battery, and added an inverter for a colour TV. The battery too big for the panels. |
| **38** | Store room/ Chair | Y/Y/Y/N | Solar x 2 | 100 | Voltmaster<br>Chloride exide | Normal | 12.71 | 30/30 | 15 | **Very bad** | No | **X, X, X, X, X, X**<br>1.27, 1.25, 1,26, 1.27, 1.26, 1.26 | All empty<br>All OK | One battery was really bad. It had been repaired. Some cells were broken. Told them to remove that one and to fix the |
| **39** | Bedroom/ Wooden stand | Y/Y/Y/Y | Truck | 120 | Exide | Normal | 12.45 | 27/27 | 13 | OK | No | 1.23, 1.23, 1.20, 1.20, 1.20, 1.20 | All overtopped | Told to wash the panels. |
| **40** | Store room/ Chair/ Carton | Y/Y/Y/N | Auto | 50 | UBL | ? | 12.80 | 30/30 | 15 | OK | No | 1.23, 1.25, 1.25, 1.23, 1.23, 1.23 | All OK | **The fuse in the CC was blown.** Probably when the first battery was removed. Told about distilled water. |
| **41** | Living room/ Wooden stand | Y/Y/Y/Y | Truck | 120 | UBL | Normal | 13.07 | 30/30 | 16 | OK | No | 1.23, 1.23, 1.23, 1.23, 1.23, 1.23 | All OK | **Bottle of battery acid next to battery.** Told about distilled water. Battery too big for panel? |

## *Appendix C*

**SURVEY FORM FOR SOLAR COMPANIES** Form number:……..

This survey form is a tool to obtain information for a research project on batteries used within solar systems in Uganda. The project is a Master Thesis Project carried out by Ms. Annamaria Sandgren, a student at Lund University, Sweden. The objective of the project is to improve the battery aspect in PV-systems, thus to enhance rural electrification. Dr. Mackay Okure, Faculty of Technology, Makerere University provides guidance.

We will appreciate your contribution to this project by filling in the form as completely as possible. All information will be handled strictly confidentially.

**1.** Name of company.......................................................................................................
**2.** Email address..........................................................................................................
**3.** Phone number..........................................................................................................
**4.** Contact person.........................................................................................................
**5.** What turnover did the company have year 2000?..........................................................
**6.** What turnover did the company have January to June 2001?..........................................
**7.** Estimate the market share the company holds................................................................
**8.** How many systems has the company installed so far?..................................................
**9.** How many systems did the company install year 2000?...............................................
**10.** How many systems did the company install January to June 2001?..............................
**11.** Is there documentation on the installed systems? Please specify..................................
.........................................................................................................................................
.........................................................................................................................................
☐ Accountants information ☐ Map ☐ List
**12.** What kind of customer is the most common one?.........................................................
☐ Institutions ☐ Domestic ☐ Business ☐ Donor agencies
**13.** What year did the company enter the solar business?...................................................
**14.** Is the company representing a foreign company? Please specify..................................
.........................................................................................................................................
**15.** Is the company a member of UREA? Yes ☐ No ☐
**16.** How many offices has the company got in Uganda, and where are they situated?
.........................................................................................................................................
.........................................................................................................................................
.........................................................................................................................................
**17.** What kind of marketing information does the company provide? Please, list specific information……...........................................................................................................
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.........................................................................................................................................
☐ Handouts ☐ Radio ☐ Seminars ☐ Adverts ☐ Other, please specify…………………
**18.** Regarding the technical information on your products:
Sources of information:………………………………………………………………………
Channels used to customers:……………………………………………………………..

**19.** Personnel details

| Designation | No. | Qualifications | Time on solar (%) |
|---|---|---|---|
| **Owners** | | | |
| **Management** | | | |
| **Engineering** | | | |
| **Technicians** | | | |
| **Sales** | | | |
| **Other** | | | |

**20.** Have the technicians had specific solar training? Please specify...................................
.............................................................................................................................
.............................................................................................................................
**21.** When installing is there a procedure to follow? Please specify......................................
.............................................................................................................................
.............................................................................................................................
.............................................................................................................................
☐ Checklist
**22.** What kinds of preparations are carried out before going to the site?..............................
.............................................................................................................................
.............................................................................................................................
.............................................................................................................................
☐ Checklist
**23.** Does the company provide a battery box and a bottle of distilled water when installing?
Battery box: Yes ☐ No ☐ Distilled water: Yes ☐ No ☐
**24.** Is there any guarantee given on the systems? If, how long?............................................
**25.** How is the after sale service organized?..........................................................................
.............................................................................................................................
.............................................................................................................................
.............................................................................................................................
☐ Checklist ☐ Preventative maintenance ☐ Included in system cost
**26.** Is there any training for the end-users? Please specify..................................................
.............................................................................................................................
.............................................................................................................................
.............................................................................................................................
☐ Written ☐ Oral ☐ Seminar ☐ Other, please specify…………………………………….
**27.** List specific instructions..........................................................................................
.............................................................................................................................
.............................................................................................................................
.............................................................................................................................

**28.** What kinds of batteries does the company sell?

| Brand | | | | |
|---|---|---|---|---|
| **Type** | | | | |
| **Sizes** | | | | |
| **Buying price** | | | | |
| **Selling price** | | | | |
| **Taxes** | | | | |
| **Rank (%) quality compared to price** | | | | |
| **Sales rate (%)** | | | | |
| **Guarantee** | | | | |
| **Average lifetime** | | | | |

**29.** What are the experiences made regarding locally produced batteries compared to imported ones?..................................................................................................................
.........................................................................................................................
.........................................................................................................................

**30.** List according to severity; problems, causes and solutions of theses problems during sales, customer contact, installation, after-sales service and upgrading

| **Problems** | **Causes** | **Solutions** |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

**31.** What happens with worn out batteries?............................................................................
.........................................................................................................................
.........................................................................................................................

**32.** Do you have any concerns regarding the lead and the acid used in batteries? Please specify.................……………………………………………………………………..
.........................................................................................................................
.........................................................................................................................

**33.** Do you provide the customer information regarding health and environmental risks on the batteries? Please specify...........................................................................................
.........................................................................................................................
.........................................................................................................................

**34.** Specify how much a solar home system running 4 lights (8 W), one TV (B/W) and one small radio would be.

| **Item** | **No.** | **Size** | **Cost** |
|---|---|---|---|
| Panels | | | |
| Batteries | | | |
| Lights | 4 | 8 W | |
| Charge controller | | | |
| Other | | | |
| Installation | | | |
| Total | | | |

**35.** How is the credit system organized (interest, payback time, etc.)?
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
☐ Working well ☐ Sufficient ☐ Needs improvements

**36.** What is your opinion on the market potential for solar systems?..................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................

**37.** Additional information.........................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................

## *Appendix D*

## *The amount scrap lead accumulated in Uganda*

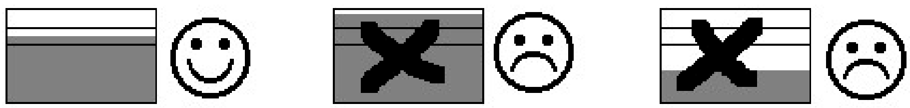
### A rough estimation of the amount scrap lead accumulated in Uganda from UBL's production each year

1. UBL only accepts the amount of scrap lead they use in the production. (Sendagala 2001)
2. The efficiency of the recycling process is approximately 70%. (Sendagala 2001)
3. Recycled lead is only utilized for the negative plates, approximately 50% of a battery's total lead content. (Sendagala 2001)
4. As a consequence of the above statements UBL is only accepting about 71% (50% / 70%) of the amount lead they sell to the Ugandan market.
5. UBL produces and sells approximately 120 000 batteries annually. (Sendagala 2001)
6. The average lead content in a battery is around 8 kg (Sendagala 2001).
7. The information from paragraph 4-6 gives that near 280 tons of scrap lead is accumulating in Uganda each year. (8 x 120 000 x (100-71%))

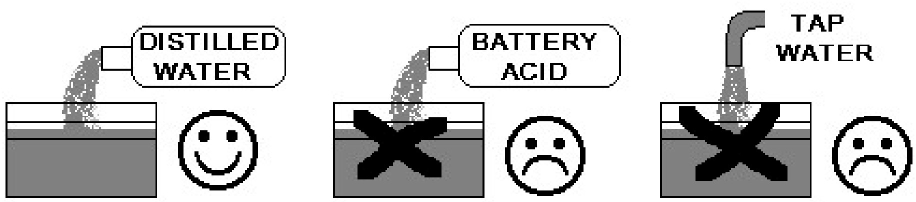
## *Appendix E: Graphic maintenance manual*

# Maintenance Manual for Solar Electric Systems

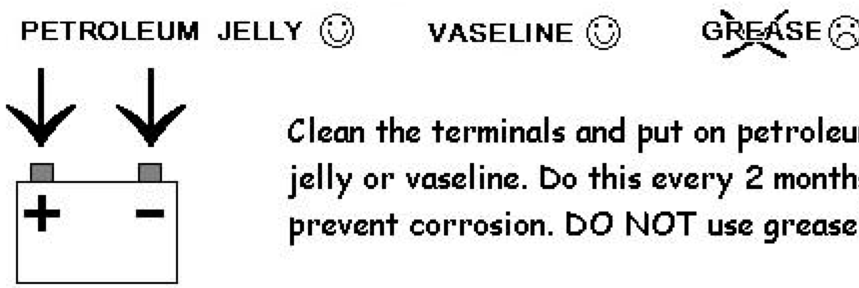
## THE BATTERY LEVEL



Check the battery level every 2 months. Top up if the level is beneath the lower level. USE DISTILLED OR DE-IONIZED WATER ONLY. Distilled water can be bought at any petrol station. DO NOT use tap water or battery acid!

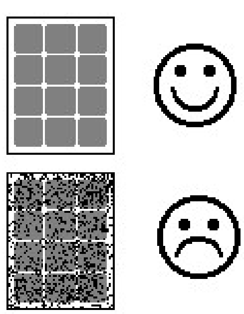



## THE BATTERY TERMINALS




Clean the terminals and put on petroleum jelly or vaseline. Do this every 2 months to prevent corrosion. DO NOT use grease!

## THE SOLAR PANEL:



The solar panel should not be dirty or dusty. Clean it every 3 months with a soft piece of cloth and clean water. DO NOT use soap and make sure not to scratch the panel.

Installing Company:............................................

Contact number:..................................................

# Abbreviations

| | |
|---|---|
| **AC** | Alternating Current |
| **AFRREI** | Africa Rural & Renewable Energy Initiative |
| **DC** | Direct Current |
| **ERT** | Energy for Rural Transformation |
| **ISO** | International Organization for Standardization |
| **Ltd** | Limited |
| **MEMD** | Ministry of Energy and Mineral Development |
| **NEMA** | National Environment Management Authority |
| **NGO** | Non Governmental Organisation |
| **PV** | Photovoltaic |
| **SLI** | Starting, Lightning and Ignition |
| **SOC** | State Of Charge |
| **UBL** | Uganda Batteries Ltd |
| **UNBS** | Uganda National Bureau of Standards |
| **UNDP/GEF** | United Nations Developing Programme/Global Environment Facility |
| **UPPPRE** | Uganda Photovoltaic Pilot Project for Rural Electrification |
| **URA** | Uganda Revenue Authority |
| **URDT** | Uganda Rural Development Training |
| **UREA** | Uganda Renewable Energy Association |
| **USD** | United States Dollar |
| **USh** | Uganda Shilling |
| **Wp** | Watt peak |