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Managing the Quality of Stand-Alone Photovoltaic Systems - Case Studies

PVPS

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

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MANAGING THE QUALITY OF STAND-ALONE PHOTOVOLTAIC SYSTEMS – CASE STUDIES

Foreword

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organisation for Economic Co-operation and Development (OECD) which carries out a comprehensive programme of energy co-operation among its 24 member countries. The European Commission also participates in the work of the Agency.

The IEA Photovoltaic Power Systems (PVPS) Programme is one of the collaborative R&D agreements established within the IEA and, since 1993, its Participants have been conducting a variety of joint projects concerning the applications of photovoltaic conversion of solar energy into electricity.

The overall programme is headed by an Executive Committee composed of one representative from each participating country, while the management of individual projects (Tasks) is the responsibility of Operating Agents. Currently nine tasks have been established. The twenty-one members of the PVPS Programme are:

Australia (AUS), Austria (AUT), Canada (CAN), Denmark (DNK), European Commission, Finland (FIN), France (FRA), Germany (DEU), Israel (ISR), Italy (ITA), Japan (JPN), Korea (KOR), Mexico (MEX), Netherlands (NLD), Norway (NOR), Portugal (PRT), Spain (ESP), Sweden (SWE), Switzerland (CHE), United Kingdom (GBR), United States (USA).

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The report expresses, as nearly as possible, a consensus of opinion of the Task 3 experts on the subjects dealt with.

SHORT ABSTRACT AND KEYWORDS

Task 3 of the International Energy Agency's (IEA) Implementing Agreement on Photovoltaic Power Systems deals with Photovoltaic Power Systems in Stand-alone and Island Applications. Within this Task, Quality Assurance of PV systems is considered to be of special interest. This document defines recommended QA procedures for stand-alone PV systems.

The study has been published in two parts:

Part 1: Recommendations based on real project experience (available on the PVPS web-site: www.iea-pvps.org);

Part 2: Presentation and analysis of the Task 3 Case Studies (this document).

Keywords: QA procedures, guidelines, stand-alone PV systems.

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1 EXECUTIVE SUMMARY

Task 3 of the International Energy Agency's (IEA) Implementing Agreement on Photovoltaic Power Systems deals with Stand-alone and Island Applications. Within this Task, Quality Assurance of photovoltaic (PV) systems is considered to be of special interest.

A strong emphasis on quality aspects is essential for the long term success of any PV project. However, stand-alone PV systems are frequently installed with little or no attention to quality issues. One of the main reasons for this is that the work required to implement quality procedures is perceived as being complicated and costly. Unfortunately, this perception gives rise to many project failures which are both costly and difficult to rectify.

As part of its efforts to improve performance by raising the standards of stand-alone PV systems, Task 3 Experts have produced a report presenting recommended practices for the management of quality stand-alone PV projects[1]. A number of Case Studies were selected by Task 3 Experts to provide examples (of good and bad quality projects) for these guidelines. This document summarises the characteristics and lessons learned from these projects.

[1] 'Managing the Quality of Stand-alone PV Systems: Recommended Practices', IEA Task 3, www.iea-pvps.org

2 INTRODUCTION

There are many stages in the supply of a PV system. Each stage must be considered as a potential source of system failure. It has been found that many maintenance and repair requirements actually result from failures in the planning, design, and installation processes. For example, during the South African Case Study, poor project planning led to the batteries being delivered without any consideration of interim storage prior to their installation. This resulted in the batteries being deposited outside, exposed to all weather conditions, which shortened the battery lifetime considerably.

In order to gain a complete picture of the present status of national and international standards, guidelines and QA procedures, Task 3 Experts completed a survey of current guidelines in their respective countries. In addition, a comprehensive study of international guidelines was undertaken by IT Power[2]. This review showed that there are no existing QA standards, beyond the generic ISO 9000 series, that are appropriate for application to stand-alone PV systems.

Task 3 therefore undertook to develop guidelines for the quality management of stand-alone PV projects, in both developed and developing countries. The guidelines are applicable to large and small projects. A series of Case Studies were also compiled, in order to demonstrate quality issues in practice. This document is a summary of those Case Studies.

3 THE CASE STUDIES

3.1 Case study 1: PV-Powered Lock Gate

Country:	UK
End-user / funding body:	Environment Agency
Project manager:	IT Power
Main contractor:	IT Power
PV Expert:	IT Power
Sub-contractor (detailed design, procurement & installation):	Dabbrook (Eng) Ltd.

3.1.1 System data

Array size:	680 Wp
Module make and type:	BP Solar, BP585
Battery size:	48V, 390 Ah (formed of 12 x 12 V, 130 Ah)
Charge controller type:	Trace charge control unit

[2] 'Survey of national and international standards, guidelines and QA procedures for stand-alone PV systems' IEA Task 3, www.iea-pvps.org

Uses of energy:	48 V Rotork DC actuator '16 A' Operator panel

3.1.2 Background

This project started when the Environment Agency approached IT Power because they wished to investigate the use of renewable energy to power their locks and asked IT Power to recommend the best source. IT Power supplied recommendations and a specification for the recommended source of power which was photovoltaics. The Environment Agency decided to implement IT Power's recommendations. A summary of the main quality issues emerging from the project is given in the following.

3.1.3 Contractual obligations

IT Power was the PV expert who initiated this project in conjunction with the end-user who also provided the finance, the Environment Agency. IT Power also acted as project manager and main contractor, taking overall responsibility for the project and signing a contract with the client. The detailed design and installation work was sub-contracted from IT Power to Dabbrook (Eng) Ltd. An Operation and Maintenance contract is in place from the Environment Agency directly to Dabbrook (Eng) Ltd. A diagram showing the chain of contractual liability is given in Figure 1.

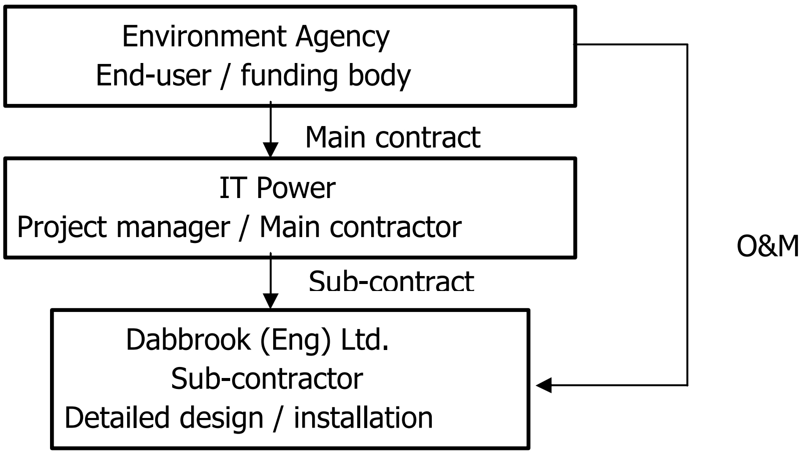

Figure 1 Chain of contractual liability

3.1.4 Design issues

A key issue to be considered during the design stage of this project was access to the site as it was a riverside location and road access was only available to one side of the river. The best location for the battery bank was the opposite side of the river from the road, so it was necessary to involve the client in providing equipment to lift the batteries to the other side of the river. An important input during the planning stage was from the Environment Agency's technicians who provided input to enable a specification to be drawn up that would meet the needs of the users.

Factory acceptance testing of the hardware was carried out, witnessed by both the client and the PV expert. The client representatives included both management and technicians, thus ensuring that the equipment was accepted at all levels within the organisation. Checking of individual components was left to Dabbrook; overall array and battery voltages were checked by the PV expert. The witnesses signed to indicate acceptance of the equipment.

IT Power approved the sub-contractor to carry out the installation work via the company's QA system which requires sub-contractors to be approved before contracts are signed with them. The approval of a sub-contractor is based on their having a good track record in previous similar work.

3.1.5 Commissioning

Commissioning of the system was witnessed by both the PV expert and the client. The PV expert carried out performance checks, checking for correct operation of the system in all modes, meeting the specification, and checking that measured values corresponded with design values. Acceptance of the fully commissioned system was signed by the client.

3.1.6 End-user training

The end-users of this system are river users and the Environment Agency technicians. Provision of training for river users was not practical, but instructions were provided, operation is simple, and there are existing locks that use a similar control system. Environment Agency technicians were trained during the commissioning and hand-over of the system. Basic training was provided covering:

- How the system works
- Main failure mechanisms (e.g. flat battery)
- Error messages

It was noted that no standard was available, so the training provided was ad-hoc. The O&M manual provides further information on operation of the system.

3.1.7 Warranties

All warranties are given by Dabbrook directly to the Environment Agency. A system / installation warranty which covers repair or replacement of any parts which fail for one year from the date of commissioning is in place. The PV modules are covered by the manufacturer's warranty of power output for 25 years and freedom from defects in materials and workmanship for five years. The other various items of equipment are covered by a manufacturer's warranty of two years for batteries, one year for charge controller and one year for the DC actuator.

3.1.8 Lessons learned

1. A disappointing outcome of this project was that a significant proportion of the system was stolen a few weeks after commissioning and after the project was publicised locally. The PV expert did recommend to the client that security measures were taken, but the client was confident that there was not a theft risk at this remote site without public access. It should be noted that there is a high risk of theft, even at inaccessible sites.
2. The role of the PV expert was found to be particularly important during this project for the checking of design work. There was no previous experience to define the torque that was required to lift the lock, and some investigation was required to obtain sufficient information from the supplier of the actuator to give an accurate sizing. The initial design, based on average design values given by the supplier, was found to be incorrect when more detailed information was supplied. These investigations were carried out by the PV expert, who was not satisfied with the initial design proposed. This shows the importance of an independent check of design details.

3.2 Case study 2: PV rural electrification pilot project in Lao P.D.R.

Country:	Lao PDR
End-users:	Villagers in Lao P.D.R. (254 SHS, battery charge stations in 6 villages)
Funding Body:	Japan International Co-operation Agency (JICA)
Executing agency of pilot project:	Ministry of Industry and Handicraft (Lao PDR)
Project manager:	PROACT International Inc. & Shikoku Research Institute Inc. (Japan)
Main contractor:	PROACT International Inc. & Shikoku Research Institute Inc. (Japan)
PV Expert:	PROACT International Inc. & Shikoku Research Institute Inc. (Japan)
Sub-contractor :	S.V.T. Electrical Engineering Co. (Lao PDR)

3.2.1 System data

Solar Home Systems (SHS)

Array data:	55 W SHS - 152 households 110 W SHS - 102 households
Module make and type:	Showa Shell Sekiyu K.K. GT-136M
Battery size:	12CT-110, 12 V, 110 Ah
Charge controller:	SCCRE-15, 15 A
Uses of Energy:	Lamp and socket (for TV, radio etc.); 110 W SHS is available for additional battery charging

Battery Charging Stations (BCS)

Array data:	Five stations (1.98 kW, 990 W, 165 W, 1.98 kW, 2.97 kW)
Module make and type:	Showa Shell Sekiyu K.K. GT-136M
Charge controller:	SCCRE-40, 40 A
Uses of Energy:	Battery (12 V-50 Ah, 12 V-70 Ah, 12 V-120 Ah) charging

3.2.2 Background

This pilot project was conducted as a part of the Study on Rural Electrification Project by Renewable Energy in the Lao People's Democratic Republic based on the agreement between JICA and the Government of Lao PDR. The final study report was submitted to JICA and the Government of Lao PDR in February 2001.

3.2.3 Contractual obligations

- Although JICA provided the finance to the project and procured PV equipment based on the tender document written by the consultants, the pilot project was designed to check the financial sustainability. The analysis assumed that the Lao Government had procured all the equipment at the market price and the assumed initial cost would be fully recovered from each under a lease-purchase contract in 20 years.
- The Ministry of Industry and Handicraft (Lao P.D.R.) is the counterpart agency of JICA and assumed the status of lessor after completion of the JICA pilot project. The project consultants made the pilot project plan and showed the Ministry how to implement the pilot project to enable them to gain sufficient knowledge on PV-based rural electrification.
- The project consultants were responsible for the pilot project, including system design, supervising installation, tariff design, organising user's association, training of users and installers and monitoring. All these tasks should be carried out by the Ministry on a large scale in the future.
- The User Association was responsible for tariff collection, capital cost repayment, periodic monitoring, and troubleshooting and record keeping. In the case of the BCS, the Association arranged battery-charging schedule of system users.
- SHS users were required to sign a lease-purchase contract and were responsible for system maintenance and battery replacement. They were asked to report any serious technical problems with the PV system to the User Association. They were responsible for paying a monthly tariff to the User Association. BCS associations were required to sign a lease-purchase contract and to collect fees from users.

3.2.4 System design

The PV systems were designed by the consultant, based on irradiation data and a socio-economic survey of energy consumption, household income and willingness to pay for PV electrification.

3.2.5 Tariff design by the consultant

A down payment was required for the SHS. This was designed to limit the users to those who would be able to afford new batteries in order to ensure battery replacement in the future.

The monthly electricity tariff was carefully designed, based on a socio-economic survey of energy consumption, energy expenditure, and household income, in order to recover the costs of the User Association (which provides the operation and maintenance service) and the initial investment.

A modest reward was given to the User Association members as an incentive for their work on tariff collection and periodic maintenance.

Long term financial sustainability of PV electrification was confirmed by the financial analysis.

3.2.6 End-user training

The consultants conducted PCM ("project cycle management", or in other words "participatory planning") workshops several times in each village in order that participants (villagers) understood the PV electrification project in terms of technology, finance, organisational structure and responsibility of participants.

The consultants assisted the villagers to organise a PV User Association in each village.

3.2.7 Logistics

The consultants conducted a preparatory survey on transportation of PV equipment. Some villages are accessible only by small boats whilst other villages are accessible only by trucks in the dry season. Therefore transportation and installation works were conducted before and after the rainy season. SVT Electrical Engineering Co., which is experienced in PV system installation in remote villages in Lao P.D.R., was hired to undertake transportation and storage of equipment and installation works.

3.2.8 Installation

The consultants designed the basic system configuration and installation method including mounting of the PV panel and in-house wiring and instructing the installers. The consultants trained the local installation staff before installation began. During the installation period, the consultants conducted further 'on the job' training as a part of the technology transfer to local installers.

3.2.9 Operation and maintenance

The PV system is very low maintenance, which is a significant advantage in the case of rural electrification. A PV User Association was set up in each village to provide guidance on system usage and maintenance, and to collect the tariff payments. The consultants held operation and maintenance training workshops for the PV User Association as well as for the users in each village.

The consultants also developed installation and maintenance manuals in Lao (local language) for the User Association. These manuals describe precautions and troubleshooting measures. A one-page instruction sheet that addresses basic O&M issues was provided to each SHS user.

3.2.10 Post project monitoring

Continuous performance monitoring equipment (data sampling: every 1 minute, data recording: every 10 minutes, data recording PC card is replaced every 2 months) was installed at one household.

Monitoring surveys on SHS and BCS performance were conducted 3 times, following commissioning by the consultants in each village.

The consultants also conducted surveys on the effects and impact of PV electrification on the villagers' lifestyle and income generating activities.

3.2.11 Lessons learned

- Battery replacement, which requires about $20 every two years, should be the responsibility of users. Tariff design and collection is a key to financial sustainability. Since "cost recovery" is most important for financial viability, it is unwise to provide electricity without at least some partial payment unless there is a social justification to do so. It can be expected that the PV users earn more income by working under the lights in the evening, which is a positive impact of PV electrification.

- It is necessary to prepare a contract form beforehand and to ask each user to sign it in order to clearly define the responsibilities of service provider and user.
- Villagers' participation from an early stage is the key to successful projects in terms of SHS design, tariff design, organising users' association, user training etc.
- It is necessary to check the availability of spare parts in the local market.
- User training on battery connection and management is a key technological issue, because most villagers in Lao P.D.R. are used to battery usage but they do not have a precise understanding of how to manage a battery and nor do they appreciate the function of charge controller.

3.3 Case study 3: Solar-diesel hybrid electrification of four rural villages in Indonesia

Country:	Indonesia
End-users:	Villagers of Muara Ancalong (Kalimantan Island), Salopankang, Kalumpang and Hialu (Sulawesi Island)
Funding:	Franco-Indonesian protocol with the Transmigration Ministry of Indonesia
Project manager:	French consortium : Photowatt, Total Energie and Transénergie (France)
Module supplier:	Photowatt
Installer:	Total Energie

The Transénergie representatives in Jakarta and France were responsible for the project management during the design and installation phases, and maintained the highest possible communication level between the Ministry of Transmigration and the French companies supplying the materials and the engineering work.

3.3.1 System data in each village

Array size:	23 500 Wp
Module make and type:	480 Photowatt PWX 500 modules
Battery size:	240 V, 1440 Ah
	(120 x 2V Oldham Hawker batteries, 1440 Ah)
Diesel genset:	SDMO 40 kVA
Charge controller type:	Ainelec charge control unit
Battery charger:	Ainelec 30 kW
Inverter:	Ainelec 30 kW

Uses of energy:	lighting and small power appliances (radio, TV set)
Monitoring:	Enerpac data logger

3.3.2 Background

Indonesia is composed of a great number of small and isolated islands where millions of inhabitants remain without electricity and are extremely unlikely to be connected in the near future due to their isolation. Within the framework of the French-Indonesian collaboration, supported by the Transmigration Ministry of Indonesia, several villages have been created to fight rural exodus of the population. Whole groups of families have been resettled in rural areas, where they are equipped with houses, food, fertiliser, implements etc., as a basis for establishing a new livelihood. Four of these villages were selected to be equipped with a hybrid photovoltaic-diesel system as a power supply. Each village is composed of three to four hundred households. Each house is equipped with three lights and one socket.

Within this context, Transénergie developed a prototype controller which aims to optimise the service provided to the end-users by managing the energy consumption of each member of the community and preventing any over consumption.

3.3.3 Contractual obligations

Technical assistance, operation and maintenance training, as well as a one year follow-up program, were provided by Transénergie in France and in Indonesia.

Transénergie was in charge of the following items:

- Design of the power station and specification of the equipment,
- Operation and maintenance programs,
- Executive training of the technicians in France and on site,
- Commissioning of the four sites,
- Reports,
- Monitoring programme.

The Transénergie representatives in Jakarta were responsible for the project management during the design and installation phases, and maintained the highest possible communication level between the Ministry of Transmigration and the French companies supplying the materials and the engineering work.

3.3.4 System design

The main characteristic of the system design is that 80 % of the total energy required is provided by photovoltaic generator; the diesel generator provides the remaining 20 % and can be used directly to supply the mini-grid in case of PV malfunction. During sunlight hours, the photovoltaic generator charges the battery storage according to the available irradiation. The inverter, powered by the battery, operates continuously and delivers electric energy with respect to the load which is quite low during the day. At nightfall, the demand increases and the genset is turned on so that the battery storage is preserved. The genset is switched off automatically when the battery state of charge has reached a sufficient level or after a programmed duration. Each day, the same operating cycle runs. The energy management system performs a full charge of the battery every three days to maintain reliability and extend life time.

In order to simplify the supervision, all the information needed to control the operation is available on the central control and distribution panel and can be visualised on control displays of each component. At the same time, a monitoring system performs several measurements and is able to transmit data and alarms to a remote control centre by a satellite modem. In order to enable the users to finance a part of the maintenance and thereby to ensure the sustainability of the system, each home is equipped with a prepayment meter which assumes three functions :

- electricity payment by keypad prepayment;
- power limitation with respect to the subscribed contract of the consumer;
- daily average energy limitation.

3.3.5 Tariff design by the consultant

The financial participation of the users is a central point needed for the sustainability of the project. The users have to pay a fee for electricity in order to finance the operating costs of the installations, such as:

- Salaries of technicians in charge of the maintenance;
- Professional maintenance costs;
- Fuel and lubricants for genset;
- Consumable parts for genset and PV generator;
- Repair and spare parts costs.

The energy payment scheme requires an organisation, adapted to local practices and constraints, to collect payments for energy. To assist with the collection of payments, Transénergie developed a dedicated energy prepayment device called the "Suncash". This innovative power meter, controls the power available to each household, and can limit the electricity consumption for a given duration. It uses a special code entered by the users on an integrated keypad (each home is supplied with a Suncash). The user must pay a fee to the village energy co-operative, which is equipped with a selling station. In return for payment, the cashier gives a code, that allows the user to program his power meter for a corresponding amount of time. The Suncash unit also allows a limit to be set on the daily consumption as, for each fee, there is a corresponding theoretical daily consumption level.

3.3.6 End-user training

Transénergie engineers provided training sessions for the villagers, concerning the most efficient ways of using the systems, including:

- General explanation of the system;
- Recommendations for using the system efficiently;
- Explanation of the pre-payment system;
- Explanation of the consumption and instant power limitation of the Suncash device.

A comprehensive user-guide was supplied to every user.

3.3.7 Operator training

On each site, two technicians are trained by Transénergie. These people had already been involved in the installation of the plant. Their role is to:

- Make a daily inspection of the plant;
- Clean the modules;
- Clear the site and clean the technical room;
- Make measurements and control bimonthly the electric boards, the diesel genset and the batteries;
- Carry out preventative maintenance of the genset (filters) and batteries (distilled water);
- Carry out maintenance in the end users' houses (lights, ballasts, energy counters).

In order to constantly improve the technical skill of the operators, a technician in charge of the supervision of the four sites comes from Jakarta (every two months then every six months) and trains them in the replacement of components.

3.3.8 Logistics

All materials were sent to Ujung Pandang in Sulawesi. The equipment was then physically divided into four separate shipments, corresponding to the four project sites. These were then shipped in maritime grade packaging. Transmigration and VTP were in charge of the equipment and material custom clearances, its storage in warehouses, and its transportation from Ujung Pandang to the final sites. The equipment arrived in full containers, that were later split for local transportation, because of the lack of container carriage.

3.3.9 Installation

Transénergie was responsible for training the partner installation teams, on this Indonesian project. A one week training session was conducted in Jakarta before the start of the first installation works. Two engineering specialists were sent on-site, for the training of the teams during the installation phase.

Transénergie, under the direction of the Ministry of Transmigration and of the local authorities, ensured the effective management of the project , including the supervision of the installation work sites, the control of the civil engineering operations, and system commissioning. Engineering specialists were present on site during the installations, and supervised the work, to guarantee its full compliance with the manufacturer's specifications and warranty conditions.

3.3.10 Operation and maintenance

Maintenance is performed at three different levels:

- Routine maintenance: the PV system requires a local technician trained by Transénergie. He is employed full time and is responsible for the basic maintenance (see "end user training" part).
- Professional maintenance: this level of maintenance is provided by a local engineer located in Jakarta. The local agent in the capital was chosen and trained on site and at his office, to carry out biannual checks on the system. He also deals with troubleshooting expertise in case there is a problem that the local technician cannot solve. This agent understands the electrical wiring diagrams provided to him, and is familiar with the sites he checks. The agent is a professional electrical contractor, or an electrical engineer with field experience.

He is also familiar with these projects and he helps the local and regional technicians in the repair and/or replacement of the major system components.

- Supervision: this third level of maintenance is provided by the local representative of Transénergie in Jakarta and by engineers of Transénergie in France (using a data acquisition unit and satellite transmission).

In the case of failure at the end user's home, the local technician comes and makes the repair. If the outage concerns the PV plant or the mini-grid, the technician informs the chief of the village, who then writes to the regional representative of the Transmigration and the representative in Jakarta.

A solar management organisation at the village / local-government level, composed of the two technicians, a treasurer and a director, is responsible for the day to day running of the project. Their activities include: maintenance, fee collection, stock management (spare parts), the information provided to the local and central government authorities if any technical or managerial problems occur, the management of fund collection, and accounting and transfer of the funds to a special bank account.

3.3.11 Project monitoring

Continuous performance monitoring equipment has been installed in each village. The data logger has a two year memory capacity for daily measurements (environmental measurements, such as irradiation, wind speed and temperature; and electrical measurements, like DC and AC current and voltage) and records detailed data (data recording: every 10 minutes) of the last two weeks. It also makes monthly and annual average calculations. These data are sent via satellite phone transmission to Jakarta and France.

The objectives of the monitoring are to:

- Determine the performance, reliability and durability of the plant and its components,
- Assess the quality of the design,
- Identify the production and consumption profiles,
- Provide information on the effective management and operation,
- Contribute to a general assessment of the PV systems.

The monitoring was conducted by Transénergie for three years following the start up of the plants.

3.3.12 Lessons learned

Positive issues:

- Installations in good shape after the first years of operation;
- Good collection of payments;
- Satisfaction of the end users;
- Technical interest of the Ministry of Transmigration and LSDE (Indonesian technical adviser for the ministry) in the global project.

Negative issues:

- Depopulation of some villages (50%) in spite of the available energy supplied, due to Asian economical crisis;

- No control of the accounts by the Ministry of Transmigration;
- Bypass of some individual energy counters;
- Vague administrative situation due to the rejection of responsibilities between national and regional delegations of the Ministry of Transmigration after the decentralisation law in January 2000.

There was a need to establish a new exploitation scheme to ensure the continuity of the system at the end of the warranty period by the end of the year 2000. All the villages are currently running well. The replacement of the battery bank after eight or ten years of operation may not be possible without a governmental subsidy.

3.4 Case study 4: Water purification in Uganda

Country:	Uganda
End-user / funding body:	Bulyansungwe Community / Together
Project manager:	Together (help organisation)
Main contractor:	ISET, University of Kassel
PV Expert:	ISET, University of Kassel
Sub-contractor (detailed design, procurement & installation):	Solartechnik-Systeme Minden

3.4.1 System data

Array size:	900 Wp
Module make and type:	Shell RSM 75
Battery size:	BAE OPzV 130 Ah (24V)
Charge controller type:	Steca Solarix 30A
Uses of energy:	Pumping and UV water purification

3.4.2 Background

The aim of the North Hesse relief organisation “Together” was to provide the 900 pupils of a rural school centre in Uganda with clean drinking water. In a non-profit collaboration, employees of the University of Kassel and ISET developed a decentralised PV-powered water supply system. All components were transported to Uganda and were assembled there by the users, supported by some specialists. Filtered rainwater is now purified by UV radiation and pumped into a water tank on a tower. A microprocessor manages the photovoltaic and battery powered system, according to demand from the loads.

3.4.3 Contractual obligations

The project initiator was the Aid organisation “Together”. They contracted the University of Kassel/ISET to do the PV system design, the testing of the system in the laboratory and the training of the local technician of Bulyansungwe community. The University of Kassel was also contracted to control the system and its operation on site after two years of operation. Solartechnik-Systeme Minden was contracted for the commissioning of the system in Uganda.

3.4.4 Design issues

The system was designed to supply water pumping, water purification and lighting of the school building. The water supply system was designed for a capacity of 4m³ per day and three hours for lighting purposes (100W). The system autonomy was designed for one day. The system is controlled by a logic controller that performs demand side management in order to minimise battery cycling and only operate the two cascaded water pumps when solar energy is sufficient.

3.4.5 Financing

The system was financed by "Together" as well as contributions from industry. The users do not pay for the system usage. It was intended from the beginning that the University of Kassel would be contracted to perform a general overhaul; among this is the exchange of batteries and exchange of UV lamps.

3.4.6 Commissioning

Technology transfer was provided from University of Kassel to the installers from Solartechnik-Systeme Minden. Commissioning was done by Solartechnik-Systeme, contracted by "Together". The local technician assisted in the commissioning phase.

3.4.7 End-user training

The installer described basic system operation to some of the staff of the school. As the main end-users are pupils (and they change regularly) there was no specific end-user training programme for the pupils.

3.4.8 Operator training

The priest and the technician from Bulyansungwe Community visited the University of Kassel. The technician stayed there for about one month where he received a one week intensive training on all the problems that could occur with the system.

3.4.9 Warranties

There was no system guarantee but a maintenance contract was placed with the University of Kassel after two years of system operation.

3.4.10 Operation and maintenance

The local technician (responsible for all the technical questions at the school building) is responsible for operation and maintenance.

3.4.11 Post project monitoring

Apart from a general overhaul two years after the system was commissioned, no post project monitoring was undertaken. The local people are not able to do it and, as the location is very remote, there is no telephone connection to enable remote monitoring.

3.4.12 Lessons learned

Although the project team was aware of the significance of system operation and maintenance, and the project manager had provided the local technician with training in Germany, it transpired that the technician was poorly selected for this task:

- He did not have basic maintenance skills prior to his training in Germany, for example, he was unfamiliar with very basic tools such as screwdrivers. In his remote home in Uganda, he never had any contact with electricity before and therefore had no need for screwdrivers.
- He wasn't able to perform a capacity measurement of the batteries although he had been trained in this task. There had not been a thorough consideration of the skills required prior to training of the technician.

3.5 Case study 5: PV electrification of rural schools in South Africa

Country:	South Africa
End-user:	Schools in rural South Africa
Funding body:	European Commission
Project manager:	South African Department of Minerals and Energy (DME)
Main contractor (detailed design, procurement, project management):	Eskom (South African electric utility)
PV Expert:	Technical Assistance Unit (TAU), provided by IT Power (International consultants) and EDG (local consultants)
Sub-contractor (installation):	Several smaller local companies
Responsibility for maintenance:	South African Department of Education (DoE)

3.5.1 System data

Array size:	880 W_p (8*110 W_p)
Module make and type:	Isofoton I-110-12
Battery size:	12V, 546 / 516 Ah
Charge controller type:	Isofoton ISOTEL 30-SD (24 V/30 A)
Uses of energy:	Lights and audio-visual equipment (TV, VCR, satellite receiver) - provided by the programme. Some schools use their own additional appliances (e.g. PCs, printers, photocopiers)

3.5.2 Background

The project described in this Case Study provided PV systems, including lights and audio visual (AV) equipment, for 1000 schools in remote areas of South Africa. Whilst many South African cities and towns are fully developed with modern infrastructure and energy services, a large number of people in the rural areas do not enjoy the benefits of being connected to the electricity grid. The South African government, together with the electric utility Eskom, are working on extending the grid in the rural areas. In parallel to grid extension, PV is used to electrify schools, clinics and also households, mainly in areas where the grid would be least economic.

The project was the EU contribution to an existing government programme (Reconstruction and Development Programme, RDP) set up in 1995 to supply non-grid electricity to 16 400 schools in remote parts of the country. Prior to the EU project, over 1 400 schools had been electrified with finance from the government's national RDP and from the Dutch government (300 schools) at a cost of approximately 12 million Euro. The EU-funded project commenced in December 1998 and was completed in mid-2002.

The objective of the project was to provide electricity to 1000 schools in remote areas of South Africa, using PV systems. As part of the PV systems, each school was to receive lights and AV equipment. The electric lights would be useful in extending study hours, especially during pre-exam periods, but also during the day on rainy days. Electric lights would also allow adult classes to be held in the evenings. The AV equipment would allow teachers and students access to educational TV programmes, and would also improve the standard of English teaching considerably.

Amongst water supply, transport and telecommunications infrastructure, electricity is seen as one of the most urgent needs for the rural communities, and is therefore part of longer-term development strategies.

3.5.3 Contractual obligations

The project was funded by the European Commission and its total value was 15 million Euro. European Commission financing included capital and installation costs of the equipment, as well as technical assistance including capacity building and initiation of a maintenance programme, including maintenance for the first year. Costs for ongoing maintenance were not included in the European Commission financing, but were the responsibility of the DoE.

The project was implemented by the South African utility Eskom, under the supervision of the Department of Minerals and Energy (DME) and with technical assistance from IT Power in the UK and the Energy & Development Group, South Africa. After the installation phase, the Department of Education (DoE) became responsible for the PV systems.

3.5.4 Capacity building

The Technical Assistance Unit (TAU) carried out capacity building at various levels. Within the DME and the DoE, technical and managerial support was provided to officials, leading to vastly improved technical capabilities and understanding of the issues involved. Similar support was provided to the relevant managers and staff at Eskom, both at Head Office and in the two Provinces.

Technical training was carried out for Eskom's commissioning personnel as well as for installation contractors and their staff, both in formal training sessions and more informally during field visits. Similarly, Eskom's extension workers, responsible for liaison with schools and training of teachers, were trained in formal training courses and on the job during visits to schools.

3.5.5 System design

The main components of the PV system installed at each school were an 880 Wp PV array, a charge controller, a 24 V battery bank and an inverter. Additional items included electrical protection equipment (e.g. circuit breakers, fuses, earth leakage detection), a display giving an indication of the state of charge of the battery, and several anti-theft and anti-vandal measures (e.g. steel enclosures, steel frame around the modules, tamper-proof bolts).

In addition to the PV equipment, lights and AV equipment were provided for each school (television, video cassette recorder, satellite decoder and satellite dish). The systems were designed to generate enough electricity to provide lighting for three to five classrooms and power for the audio-visual equipment. Electrical wiring of lights and sockets, including an electrical distribution box, was included as part of the PV installation package, as was the installation of the satellite dish. Only one standard size was provided; the fact that schools vary considerably in size and also in the number and type of additional appliances they want to connect was not considered.

3.5.6 Quality assurance mechanisms

Eskom developed procedures for both the testing of equipment and the installation and commissioning of systems at the beginning of the project. About one year after the start of the project, the TAU had been contracted and commenced its activities. Part of the TAU's remit was ongoing monitoring and evaluation of the project. During the initial months of the TAU's activities, serious shortcomings and obvious technical problems became apparent, including lack of quality control in equipment selection and approval, procedural short-comings resulting in variable quality of systems in the field, and variable levels of training for installers and users. Existing procedures had either proved inadequate or sometimes had not been followed at all. The results were evident in a high numbers of system failures in the field, and the long-term implication was higher operating costs or premature system failure.

In addition, analysis of feedback from the field indicated that theft and vandalism occurred to a much larger extent than previously realised, and were becoming a threat to the success of the project. Upon the TAU's recommendation, the DME called an internal review to address the problems discovered.

During the review, the issues identified were dealt with by the TAU in co-operation with Eskom and other stakeholders. Over a period of several months, design improvements, component matching and component testing were carried out, and a number of quality assurance processes were improved. To facilitate this, the TAU produced procedures for component checks, for battery storage and regular recharging, for installation, and for more detailed commissioning checks. Eskom and installation subcontractor staff were then trained in using the new procedures.

The basic principle of the quality assurance mechanisms put in place during the review was to follow documented procedures, and to record the results of all tests and checks carried out. Any shortcomings were recorded, to be rectified prior to completion of installation and handover of the systems. The TAU carried out spot checks as part of its audits, to ensure that procedures had been followed correctly.

Before the end of the TAU contract, the TAU carried out a set of final audits to check whether systems had been installed and commissioned correctly, applying the relevant procedures. It was found that the technical quality of the installations had improved greatly between the initial schools visits and the final audit visits. However, significant problems still remained at a number of schools at the time of the TAU's final audit. Due to delays with the installation process, the TAU contract ended several months before installations were complete, with significant numbers of installations still to be completed. Therefore at the end of the project a large number of installations were completed without any technical audit mechanism in place.

3.5.7 Security

Following the experiences during the first year of the project, as well as in previous projects, security was recognised as a major problem by all stakeholders. The TAU therefore implemented a number of security measures.

In addition to the array security frame and the steel enclosures provided, each school was expected to implement a number of security measures before the AV equipment was installed. These included fences, burglar bars on classroom windows and a night watchman.

Other strategies were investigated and taken forward, such as the utilisation of Community Police Forums and district teacher networks on security issues.

3.5.8 Community involvement and end-user training

In order to try and foster a community approach and good contact with teachers and communities, the European Commission funded eight Extension Workers (EWs), who were a key link between the beneficiaries and Eskom. The main functions of the EWs were:

- Liaison with communities and setting up links;
- Monitoring and reporting function;
- Promotion of security measures at the schools;
- Training of teachers in operation and maintenance.

The TAU supported the EWs, by making visits to schools with them, maintaining a dialogue with them and their managers, and providing input to various training and re-orientation courses. The TAU also initiated reporting mechanisms to allow feedback from each school visit to be recorded and analysed.

The TAU carried out a survey of schools, interviewing staff and community members on aspects of installation, operation, installer maintenance and their own care of the PV equipment, and assessing the overall impact of the project on the schools and the communities. The utilisation of the AV equipment for the school as well as for the community as a whole, for instance through evening classes or community functions, was encouraged.

Stakeholder workshops were organised, aimed to bring together key players in order to develop a realistic maintenance strategy, to address the issues of theft and vandalism and to stress the importance of community involvement. The workshops also aimed to inform DoE decision-makers about the benefits that the PV systems would bring to the schools in terms of helping to meet the DoE's priorities and policy objectives. The workshops involved participants representing the police, DoE, Eskom, schools, DME and the European Commission. The workshops resulted in the development of a Sustainability Action Plan.

3.5.9 Operation and maintenance

The schools themselves were responsible for very basic maintenance such as topping up the batteries and cleaning the modules, and teachers received training to carry out these tasks. The quality of this 'first-line maintenance' was found to be dependent on the interest of the schools' principal or the teacher in charge.

During the first year after commissioning/handover, responsibility for maintenance rested with Eskom and the installation subcontractors. Thereafter, the DoE became responsible for maintenance. As the DoE was given this responsibility without prior involvement in the project, the TAU found that the DoE was not very well prepared to take on this task. In addition to the lack of knowledge and expertise, the DoE was also overstretched already in terms of demands on its resources, and did not have funds available to cover additional responsibilities.

The TAU provided information on the maintenance requirements to the DoE, and investigated different maintenance management options and their costs. A series of stakeholder workshops were held at which maintenance options were presented and discussed with the DoE. The TAU provided support in developing a maintenance plan to give optimum performance regarding quality, cost and speed of repair. The TAU also liaised with the DoE on issues relating to handover of the system to them, including the transfer of stocks of spare parts previously held by Eskom.

The TAU was instrumental in the development of an information management system (IMS). This served as a very useful management tool during the latter phases of installation, as well as for ongoing maintenance, and a demonstration version was presented to the DoE by the TAU. A technical manual, also prepared by the TAU, was handed over to the DoE. This provided technical data and information on the maintenance needs of the systems. It also provided information about fault-finding and could be used as a reference on any aspect of the system.

3.5.10 Warranties

Warranties were as follows:

PV modules	10 years
Charge controller and inverter	5 years
Battery	2 years
Lights and other electrical components	1 year
System installation / workmanship	1 year

3.5.11 Lessons learned

A number of sustainability issues were addressed during the implementation process, such as end-user training, long-term project responsibility, stakeholder involvement and maintenance aspects. This improved the prospects for the long-term sustainability of the project significantly. The final level of sustainability achieved and hence the success of the project depends on a number of factors, namely the technical quality of the installations, whether the DoE operates an effective maintenance scheme and makes funds available for this, and whether the stakeholders involved continue to perform their respective roles, particularly regarding effectively combating theft and vandalism.

Following lessons learned from this project, a number of recommendations are made for future PV electrification projects for schools.

a. Project design

Future PV implementation projects or programmes should be designed together with key receivers at a very early stage in the decision-making process, so that it ties in with policy objectives of the receivers, and that the project is a priority for them. This should ensure the required buy-in and long term commitment of the key receivers.

For future projects, the project design should ensure that electrification is ‘quality driven’ rather than ‘quota driven’, i.e. the main performance indicator should relate to the quality of installations rather than to the number of systems.

Technical assistance should be built into the project activities at every stage, from the planning stages until operation and maintenance mechanisms are well established. This project would have benefited from technical assistance being available from its beginning, and until after handover of the systems to the DoE. The TAU began operating about one year into the project. By this time, not only had all equipment been selected and accepted, but several hundred systems had been installed. There were therefore severe constraints with regards to possible remedial actions to address the shortcomings which were discovered at the beginning of the TAU activities. The TAU contract ended several months before installations were completed. It would have been beneficial to have technical support as well as independent scrutiny until all installations were complete, and during the first few months after handover of the systems to DoE.

b. Institutional issues

For future PV electrification projects for schools, electricity needs should not be assumed, but rather evaluated in co-operation with key receivers. Rather than to propose one single standard power supply for each school, it may be better to provide a range of services according to the types of school.

Key constraints such as theft and vandalism should be acknowledged and addressed at the project design stage, using social as well as technical solutions.

Effective ongoing maintenance is essential in order to ensure the medium to long-term sustainability of any PV project. This includes clearly defined fault reporting.

c. Quality assurance mechanisms

Technical reliability of equipment and long maintenance intervals should be key requirements. Vandal and theft proofing of each component should be given very high priority when equipment is selected, using existing technical solutions where possible. Testing of equipment and component matching should be carried out prior to final equipment acceptance.

Detailed procedures for acceptance testing as well as installation and commissioning checks must be provided, including clear guidelines for the documentation of these activities. These procedures must provide for any shortcomings to be reported, and mechanisms for their rectification prior to handover.

Reporting and monitoring are critical. It is strongly recommended that sufficient resources are allocated for these tasks. Monitoring activities should include the use of a computer-based Information Management System, which should comprise comprehensive and up-to-date data on all aspects of the project and include relevant existing information from other sources. It would then form a valuable tool for use during planning and implementation as well as for operation and maintenance.

Regular audits by an independent party are recommended, to ensure that procedures are followed correctly. An end of project audit after completion of the implementation phase is suggested, i.e. after installation, commissioning and all related activities such as training have been completed.

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