IEA INTERNATIONAL ENERGY AGENCY

Managing the Quality of Stand-alone Photovoltaic Systems - Recommended Practices

PVPS

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

Report IEA PVPS T3-15:2003

MANAGING THE QUALITY OF STAND-ALONE PHOTOVOLTAIC SYSTEMS: RECOMMENDED PRACTICES

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, with examples from Task 3 Case Studies (this document);

Part 2: Presentation and analysis of the Task 3 Case Studies (available on the PVPS web-site: www.iea-pvps.org)

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

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CONTENTS

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 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.

A previous Task 3 study[1] has shown that there are no QA guidelines specifically intended for managing stand-alone PV projects. Task 3 has therefore produced a set of QA guidelines for stand-alone PV project managers. The document aims to provide simple but effective guidance in order to implement quality procedures within a realistic project timeframe. Implementing these procedures will be less expensive than solving the problems that result when quality issues are not properly addressed.

It is intended that the recommendations contained in this document are as realistic and effective as possible. They have been brought together based on the experience of Task 3 experts and using experience from the Task 3 Case Studies. Examples of selected Case Studies with both good and poor quality procedures are presented in a separate document, which is also available on the PVPS web-site[2].

RESUME

Au sein des activités de la Tâche 3 du programme photovoltaïque de l'Agence Internationale de l'Energie consacré aux systèmes autonomes, une attention toute particulière est portée aux questions relatives à la gestion de la qualité de ces systèmes.

Il est essentiel qu'un effort important soit consacré à la manière d'assurer la qualité des systèmes dans la mesure ou l'on souhaite qu'ils puissent assurer à long terme les services que l'on attend d'eux. Sur le terrain, on s'aperçoit que de très nombreux systèmes installés ont fait l'objet de peu d'attention sur ces aspects qualité. L'une des raisons de cet état de fait est que les démarches de gestion de la qualité sont perçues comme compliquées et coûteuses et ne sont donc pas systématiquement

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

[2] 'Recommended Practices for Managing the Quality of Stand-alone Photovoltaic Systems – Case Studies', IEA Task 3, www.iea-pvps.org

mises en oeuvre. Ceci conduit malheureusement à l'émergence de nombreux dysfonctionnements qui sont, eux, à la fois coûteux et difficiles à traiter.

Une précédente étude conduite par la Tâche 3 a montré qu'il n'existe pas de recommandations ciblées sur les spécificités de projets mettant en œuvre des systèmes photovoltaïques autonomes ; c'est pourquoi il a été proposé d'élaborer un ensemble de propositions à l'attention des responsables de projets d'implantation de tels systèmes. Le présent document a donc pour ambition de proposer des repères simples mais efficaces pour mettre en place une gestion de la qualité dans un cadre réaliste. La mise en œuvre de ces recommandations coûterait moins cher que le traitement des ennuis occasionnés lorsqu' aucune disposition minimum n'est prise pour gérer la qualité.

L'intention des auteurs est de faire état dans ce document de propositions les plus réalistes possibles. Ces dernières résultent de la mise en commun de l'expérience vécue par les membres du groupe de travail de la Tâche 3, s'appuyant sur des faits réels, dont certains sont présentés à travers des cas dont on trouvera la description sur le site iea.pvps.org .

2 INTRODUCTION

2.1 What is 'Quality'?

The term 'Quality' has various meanings to different sectors of industry. Often this description is used to refer to the ISO 9000 series of Quality Management Guidelines. However 'quality' is also used to describe components and systems which comply with IEC or other standards. In this document, the quality management of a PV project includes both of these issues, as well as covering aspects which are particular to PV. It refers to maintaining the consistently high quality of the whole PV project or programme, which requires consideration of the entire project life-cycle, from planning and design through to component selection and operation and maintenance.

A Quality Assurance approach allows control of the quality of design, construction and operation of a stand-alone power plant, by systematically implementing such actions as required in order to be able to trace events as well as for prevention, verification, and validation (written documents, follow up sheets, etc.). It further enables evidence of the said actions to be provided to system owners and users.

To guarantee the quality level of an installed system each party must have a contractual responsibility: from the identification of energy-service requirements, through to installation, operation and maintenance activities. In addition it is important that the owner and / or operator of a stand-alone PV system has a vested interest in the project, in order to ensure the correct planning and maintenance of the system. The user also needs to be educated as to technology options, limitations and capabilities, as well as understanding basic maintenance requirements. The importance of education and training in the assurance of quality must be emphasised.

2.2 Why implement quality procedures ?

A strong emphasis on quality aspects is essential for the long term success of a 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 extremely costly and difficult to rectify. Such failures result in stand-alone PV systems having a reputation for poor reliability.

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 (see Part 2 of this report), 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 the same project, insufficient attention to the system design and poor product selection resulted in the specification of incompatible components.

It is widely accepted that the continued development of markets for stand-alone PV systems can be enhanced by the introduction of national or international standards and QA procedures. These lead to continuous improvement in the quality of PV systems and components installed. The markets of the future will be considerably expanded if the systems sold today are reliable.

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

Scope of document

This document sets out minimum requirements to ensure the quality of stand-alone PV systems. The recommendations section uses a listing format in order to provide a quick and easy reference for project designers and managers to check that all QA issues have been addressed by their project. The report will cover non-technical and technical issues. It should be noted that the frequent lack of attention to non-technical issues causes some of the most common problems.

This document aims to provide simple but effective guidance in order to implement quality procedures within a realistic project timeframe. Implementing these procedures will be significantly less time-consuming than solving the problems that can result if quality issues are not addressed appropriately at the various stages in the project.

This guide can be applied to projects or programmes of any size, as quality management principles are the same for projects of any size. For smaller projects, many aspects will be simplified, whilst still adhering to the same principles.

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

3 ROLES AND RESPONSIBILITIES WITHIN A PROJECT

3.1 Introduction

An important aspect of quality management is to ensure that the roles and responsibilities of all participants in a project are clearly defined. The most common reason for an aspect of a project being overlooked and causing a problem is that all parties believed it to be someone else's responsibility.

This section gives an overview of possible players and their roles in a stand-alone PV project. There are many types of PV project and the relationships and responsibilities of the different players vary accordingly; the terms used to describe the responsibilities are therefore quite general and are not intended to be prescriptive.

A PV project must always involve an engineer to undertake the technical design. However, the person who will take responsibility for other important aspects of the project such as training and logistics is less clear. This section defines each project role to ensure that all responsibilities are clearly allocated. For smaller projects, one person may take on more than one role, and the project manager may carry out many of the tasks. For larger projects, some of the roles may require a team rather than an individual.

The government (or government departments) of the country in which the project takes place may also become involved in a project, for instance if permission is required for the installation. It is also possible that the government will provide funding for a project.

The concept of Energy Service Companies (ESCOs) is currently popular. An ESCO may manage all aspects of a project, from planning through to operation and maintenance. The ESCO may also have ownership of the systems whilst providing electricity as a service to the user. This is especially attractive as the ESCO will have responsibility for ongoing maintenance and should ensure that all systems are operational for the lifetime of the project.

3.2 Main roles

The three main roles in a project are typically Financier, Implementer and User. There may be variations, for example, the User may also be the Financier (e.g. a telecommunications company building PV-powered repeater stations). In addition, especially for larger projects, expert advisers may be required to provide independent advice to the Financier and possibly to the Implementer.

Financier or Funding Body

Funding for stand-alone PV systems may come from governments and aid agencies as well as private investors. The final owner of a PV system must therefore be defined in the planning phase.

Responsibilities: provides finance, defines final system ownership

Implementer

The implementer may consist of one organisation providing all of the services required. Frequently, however, it consists of a main contractor with subcontractors providing services such as installation or supply of equipment. The role of the implementer is described in Section 3.3 in more detail.

Responsibilities: overall responsibility for the design and installation of systems.

System Ownership

There are various different players who can take on the ownership of a PV system. For example, the owner may be the same as the end-user, but the system might also belong to the funding body, a utility, an energy service company or to a government department.

For a PV project to succeed, it is important that the right actors have complete or partial ownership of the system, and that these people are also given at least some responsibility (and training) for the operation and maintenance of the system.

Example 1
In the South African PV schools project (see Part 2: Case Studies), the Department of Mines and Energy was responsible for the implementation of the programme, whilst the responsibility for maintenance was allocated to the Department of Education. However, poor planning and a lack of capacity building in the project meant that the provincial Departments of Education were only involved long after the project had started. The consequence of this was weak commitment from the Department of Education and uncertainty about how maintenance would be funded in the long term.

User

The users will use the system in the forthcoming years and therefore their needs should be paramount throughout the project. The user may also have ownership of the system and may be in charge of maintenance.

Responsibilities: using the system responsibly, first line maintenance

3.3 Roles within the implementing organisation

The roles below may exist within the implementer or implementing organisation. Depending on the size of the project, one person may perform several or even all of these roles; or for a larger project each of the roles may require several people.

Project Manager

Responsibilities: overall responsibility for all aspects of the management of the project; overall responsibility for QA for all stages of the project; responsible for project planning.

Logistics Manager

Responsibilities: ensuring all orders are placed and components delivered to the right place and on schedule; ensuring adequate storage is available at delivery site.

Project Engineer

Responsibilities: system design; quality control of hardware; supervision of installation; commissioning (or assigning third parties to carry out specialist commissioning); ensuring warranties are in place; ensuring adequate arrangements are made for operation and maintenance; performance assessment (where appropriate).

System Installer

Responsibilities: producing a 'method statement' or written procedure of how the installation will be conducted with due attention to Health and Safety issues; carrying out the installation to a high standard.

3.4 Additional roles

Depending upon the type of project, some or all of the following roles may be required:

Independent PV expert

Projects often require advice and management from a PV expert who can provide independent advice on various aspects of the project. This person has a key role to play, which may be overlooked as it is possible for a client to go straight to a supplier without the need for a third party. However, suppliers have an interest in selling their equipment, so there is frequently a need for a project to be checked by someone else in order to ensure quality. Many factors can be easily overlooked without this independent check.

Independent external advice may also be required in other areas of the project, for instance to carry out quality control

Example 2: PV Lock on a UK River
In a UK project involving the design of a PV powered lock (Case Study 1), an independent PV expert proved to be essential in the assessment and approval of the design proposed by the supplier of the PV system. The PV expert was not convinced that enough power could be provided by the PV system to operate the lock; upon further investigation it was found that additional capacity would have to be installed for the system to function correctly.

Example 3: South African PV Schools
As part of a European Aid funded programme, 1 000 PV systems were installed and commissioned on South African Schools over the period 2000 – 2002 (See Part 2: Case Studies). An independent PV expert was employed six months into the programme in order to address a number of early difficulties.

The independent expert was able to identify a large number of fundamental problems in the design and implementation of the programme and called a halt in the installation phase until these quality aspects had been addressed. Over the subsequent phases of the project, the independent expert proved indispensable to the smooth running of the project.

checks of installations, and for non-technical aspects of the project.

Responsibilities: Overseeing technical aspects of the design, providing independent input to ensure the project runs to plan, independent assessment of the quality aspects of the project, third party observation of system commissioning, providing independent advice to all parties concerned.

Trainers

There may be a need to provide suitable training for various players, such as installers or users. Ideally the training bodies should be accredited by an approved organisation.

Responsibilities: provision of adequate training for all parties involved in the project.

Key Questions to Consider:

- Who will be the owner of the PV system?
- How will the energy be paid for?
- How will maintenance costs be covered?
- How will faults be reported?
- Who will be responsible for the project once it is installed?
- Who will train the users and technicians?

Hardware suppliers

Suppliers who are able to provide quality hardware should be selected.

Responsibilities: supply of suitable components as specified and to schedule, should be able to provide documentation to show accreditation of hardware supplied.

Accredited training and testing organisations

Accredited bodies have a very important role to play in the assurance of quality. Their contribution may be required in the areas of training (or certification of training) or testing. They must be able to provide documentation to demonstrate accreditation.

Responsibilities: provision of accredited training and/or testing.

4 RECOMMENDATIONS

This section lists recommendations for quality project management, split into typical stages of a project. Figure 1 (see following page) illustrates the stages of a project, showing the key players that might be involved at each stage.

Documentation is an important aspect of any quality assurance system. It ensures that all aspects of the project are recorded appropriately and that the necessary information is available for anyone needing to carry out work on the system at a later stage. Documentation required at each stage of the project is given in the appropriate section.

4.1 Classification of recommendations

The following sections use the stages identified in Figure 1 to outline the key quality issues which should be considered at each stage to ensure project success.

The recommendations have been classified into two categories: Compulsory and Recommended. This type of system has been used previously in PV standards work[4] and is felt to be an effective means for ensuring that the recommendations are selected according to the project circumstances.

Compulsory requirements (**C**) are essential to ensure the success of a project or programme. Failure to meet these requirements could lead to failure of the project, and they constitute a minimum core of requirements which must be fulfilled anywhere in the world.

Recommended requirements (**R**) lead to optimisation of a project. Most of these requirements are universally applicable, and failure to meet them would lead to increased project costs. However, the application of these requirements should be reviewed for each particular case, taking local conditions into account.

[4] Universal Technical Standard for Solar Home Systems, Instituto de Energia Solar, EC THERMIE B report SUP 995-96

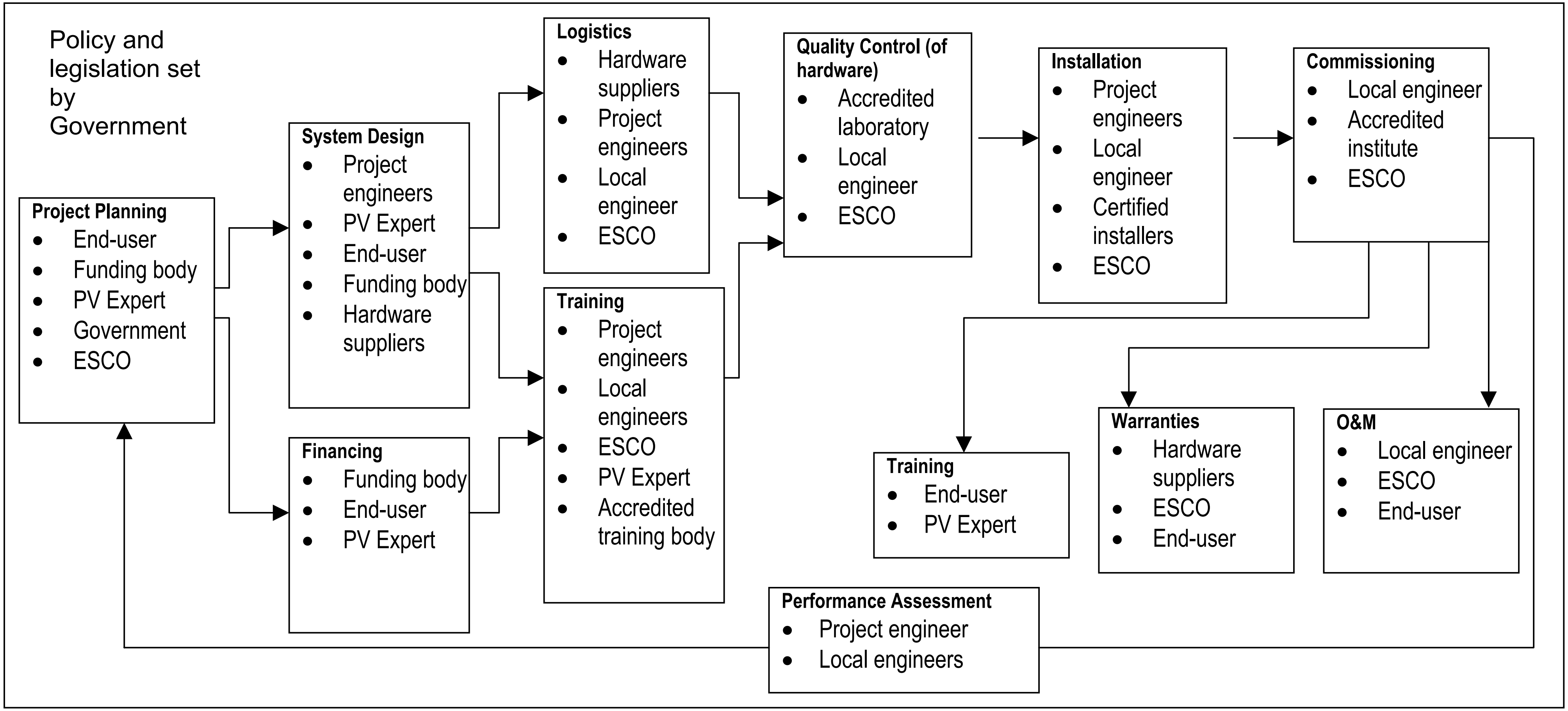

Figure 1: Stages and Key Players in a PV Project

4.2 Project planning

Documents to be provided at this stage: project plan, system description

The project planning stage will define the way in which the project is implemented. It is therefore essential that correct quality procedures are put in place at this stage of the project, as it is very difficult to implement them retrospectively. Maintaining appropriate quality assurance documentation ensures that all parties can demonstrate fulfilment (or otherwise) of their contractual duties.

1. At the outset of a PV project, care should be taken to define the contractual responsibilities of all organisations involved in the project, and to ensure that appropriate mechanisms are in place so that each organisation is answerable for any problems ensuing from their work. If the roles and responsibilities are not adequately defined, then any problems which arise will be difficult to rectify. Contracts should be in place as appropriate. (**C**) ⇨ *Impact on project lifetime*

2. The organisations required to work on a specific project should be identified and involved in the project at the correct time. If this issue is not considered, the entire project is at risk of failure. For example, the end-user / operator should be involved at the beginning of the project (Project Planning Phase) and the project engineers would be required during the Project Design Phase. A 'Gantt' chart is a useful planning tool in the identification of project stages and staff required. (**C**) ⇨ *Appropriate Design*

3. The key organisations involved in implementing a project must be able to demonstrate long term commitment to its success, to ensure that the requisite expertise and spare parts remain available throughout the project lifetime (see Example 4) (**C**). ⇨ *Impact on project lifetime*

4. The project planning team should survey and understand local energy usage before proposing a new source of energy. (**C**) ⇨ *Project feasibility*

Defining Essential Responsibilities:

a) A project leader should be identified who will assume responsibility for overall project planning (technical and non-technical issues).

b) It must be defined at the outset how the system will be maintained after installation, and who will be responsible for this task.

c) It must be defined who will be responsible for the project after installation. If possible, this person should be involved at planning stage or at least prior to commissioning. This person must have access to all technical information, e.g., warranties, drawings and contact details of suppliers.

Example 4: South African schools
In a recent South African project (see Part 2: Case Studies), where PV systems were installed on remote schools, the hardware supplier maintained a local office for the installation period only. Following completion of the installation phase, the hardware supplier shut down the local office and effectively prevented future access to spare parts and technical help. This action is likely to shorten the lifetime of the project substantially.

5. The economic analysis must assess whether the energy bill will cover the cost of the energy and also bring in enough money for maintenance, replacement of the batteries and other ageing components. (**C**) ⇨ *Project economics*

6. The planning team should allow sufficient time in the project schedule to enable testing of the necessary components and to carry out the system design approval. (**C**) ⇨ *System reliability*

7. The planning team should consider how the fuel will be transported for the diesel generator (for a hybrid, if applicable). In addition, they should consider the cost and availability of fuel. (**C**) ⇨ *Project feasibility*

8. The planning team must assess how the users will pay for the energy, and how much they will be able to afford. This assessment dictates what type of PV system will be most appropriate (e.g. level of sophistication), what the budget should be and how it will be financed. The assessment should also ensure that the users will continue to be able to afford it in the long term. (**C**) ⇨ *Project economics*

9. Public liability insurance must be in place. (**C**) ⇨ *Health and safety*

10. The planning team should estimate what will be the effects of the additional source of energy, e.g. how will it affect income-generating activities, population growth, migration, environmental effects, etc. This is important for a rural electrification programme. (**R**)

11. Insurance against theft and damage should be considered. (**R**)

4.3 Financing

Documents to be provided at this stage: project budget, payment schedule, cash flow analysis (over project lifetime)

1. Provision of sufficient funding for the project must be secured, including hardware and installation costs as well as any related costs such as project management, independent external advisers, or user-related activities. (**C**)

2. It is essential to conduct a financial analysis over the project lifetime: this should include payback period and tariff design. Consider financial sustainability of the project using financial tools such as IRR (internal rate of return). (**C**)

3. Consider different ownership scenarios to assess how the financing will be organised, e.g. end user versus ESCO ownership. (**C**)

4. Ensure the budget includes sufficient funding for testing and training, and system commissioning. (**C**)

5. Ensure that there is sufficient funding for system management, operation and regular system maintenance, including provisions for the replacement of components. This is very important in order to ensure the long term sustainability of any project. (**C**)

6. The budget should include an allocation to cover public liability insurance. (**C**)

Cash Flow Analysis

- Cash flow analysis is used to assess incoming and outgoing funds over the project lifetime (at least 20 years, based on a crystalline PV module).
- It is a useful tool to quantify the total cost over the project lifetime and to assess unit energy costs and IRR.
- The costs may be discounted in order to assess the Net Present Value of the project costs.
- All of the maintenance requirements and replacement parts must be clearly identified in the cash flow.

Example 5: Financial analysis of SHS project in Lao PDR

A Solar Home System pilot project in Lao PDR was initiated by JICA (Japan International Co-operation Agency) to assess the financial sustainability of PV electrification projects.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Initial Investment [USD]	15,270																			
Capital cost [USD]	15,000																			
Spare parts [USD]	270																			
O&M cost [USD]	92	92	92	92	92	112	112	112	112	112	1,862	132	132	132	132	152	152	152	152	152
Salary [USD]	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
Administrative cost [USD]	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
Maitenance cost [USD]	0	0	0	0	0	20	20	20	20	20	40	40	40	40	40	60	60	60	60	60
Controller replacement [USD]	0	0	0	0	0	0	0	0	0	0	1,750	0	0	0	0	0	0	0	0	0
Total cash out [USD]	15,362	92	92	92	92	112	112	112	112	112	1,862	132	132	132	132	152	152	152	152	152
Downpayment [USD]	1,000																			
Yearly fee [USD]	973	973	973	973	973	973	973	973	973	973	973	973	973	973	973	973	973	973	973	973
Total cash in [USD]	1,973	973	973	973	973	973	973	973	973	973	973	973	973	973	973	973	973	973	973	973
Net cash flow [USD]	-13,389	881	881	881	881	861	861	861	861	861	-889	841	841	841	841	821	821	821	821	821
IRR [%]					-38%					-10%					-4%					1%

Assumptions:
Number of households: 50
Unit price: USD 300
Spare parts:1 module, 2 sets of control equipment
Salary: 3 persons, USD 1.33/person/month
Running costs: fuel for motor bike etc
Charge controller: USD 35
Battery and Lamp: owned by each household
Down payment: USD 20, monthly payment: USD 1.62

System design

Documents to be provided at this stage: system specification, component specifications and datasheets, design documentation / drawings

At the design stage, the quality aspects of all other stages of the project should be considered – it is impossible to ensure a high quality installation if the system is poorly designed and difficult to install.

1. Ensure that the design phase involves the selected project design engineers, the PV expert assistance (if applicable), and the end-user (to define the load profile and local conditions). (**C**)

2. Prepare comprehensive plant documentation with details of all the components used. (**C**)

3. System design is very important. Components (even if they are certified or from the same supplier) do not necessarily work together in a system. Particular attention needs to be given to setpoints of different components such as the battery, controller, inverter and fuses. Issues such as system sizing will require expertise and need to take local climate and other conditions into account. Refer to relevant national and international standards[5]. (**C**)

4. Select components which adhere to current national and international standards, if available[5]. (**C**)

5. Use locally manufactured components if possible, but ensure compliance with relevant standards (e.g. charge controllers, lamps, batteries). (**R**)

6. Select components that have already been used widely with success in the field (preferably with respect to the local conditions). Do not use prototypes. (**R**)

7. Prepare a list of spare parts of all critical components. (**R**)

8. Consider access to site; it must be possible to deliver all components selected to site and store them appropriately. (**R**)

Example 6: Hybrid PV-wind-diesel project in Brittany

A PV-wind-diesel hybrid system has been installed on the island of St Nicolas de Glénan (Brittany) to supply energy for residential and economic activities. The energy management assumptions were:

- the users would use energy efficient appliances
- the users' daily energy consumption would be limited (by contract)
- the electricity would be used to run appropriate loads (e.g. non-heating)
- the control system prioritises the renewable resource
- the diesel genset is only allowed to run at certain times to limit noise; at all other times the renewable energy components must be sized to supply the full load.

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

9. Consider the use of large modules where possible with pre-assembled interconnection cables, hence simplifying installation and minimising the possible points of failure. (**R**)

10. Choose a simple, reliable design, using local resources wherever possible. (**R**)

11. The energy management assumptions should be clearly defined and documented (cf. Example 6). (**R**)

12. The meteorological data used for PV system sizing should be clearly recorded, along with the principles and software used. (**R**)

13. During the design phase, due consideration should be given to system security because theft of (and damage to) PV systems is a common problem. (**C**)

4.5 Training

Documents to be provided at this stage: training manuals, training certificates

Training is one of the most important aspects of ensuring the success of a project, and one that is often neglected. Training of installers is essential to ensure that high quality systems are installed. Training of users is necessary to avoid misuse of components, and to ensure that they get the best from their system.

1. The planning team should assess the level of competence of the people involved in order to prepare training courses adapted to them. (**C**)

Example 7: Capacity Building in Laos
The JICA PV rural electrification project in Laos provided ongoing installation training to local technicians as well as basic O&M training to the PV User Association.

Example 8: Capacity Building in the UK
The UK Environment Agency commissioned a project to install PV on a river lock. By providing further capacity building / training of Environment Agency staff, additional projects of this type will be readily identified in the future.

Benefits of Training

- User training: - the users become able to manage their energy needs in order to get best out of the system. In addition they are able to identify a potential system fault and to carry out basic maintenance.
- Installer: - the installer can install quality systems and conduct self acceptance tests
- Implementing organisation: organisations such as utilities are trained to manage and implement PV projects
- Maintenance staff: local staff are trained to provide O&M support to the users, to ensure smooth operation of the PV system.

2. For any project, the opportunity should be taken to provide PV training and capacity building to all key staff and organisations. This ranges from the training of local government offices in how to recognise potential PV applications, to the training of local technicians

to the training of local technicians in PV O&M issues.

3. The system installers should receive training appropriate to their needs. This should include conducting acceptance tests of completed installations (**C**)

> **Frequency of Training**
>
> **Example 9: Laos PV electrification**
> Local technicians are trained prior to start of the project and then trained further 'on-the-job' during installation.
>
> **Example 10: Indonesian follow up training**
> In order to constantly improve the technical skill of the local operators, the chief technician provides retraining every six months in the replacement of spare parts. This ensures that existing staff have refresher training but also that any staff changes are accommodated.

4. The system users and maintenance technicians should be trained by the project designer / PV expert assistance. (**C**)

5. All training courses should be accredited where possible[6]. (**R**)

6. The user will need to be educated regarding technology options, limitations and capabilities. (**C**)

7. The users should be trained in how to manage their energy and how to select appliances. One objective of this training is to reduce the energy demand of the loads. (**C**)

8. The users should be given guidance on how to pay for / finance their energy usage. (**R**)

4.6 Logistics

Documents to be provided at this stage: component delivery schedule

Poor management of logistics can affect the quality of a project. If components are not delivered to schedule and to the appropriate place, this can mean that time is lost and has to be regained later in the project. This can mean that crucial aspects of the subsequent project stages are omitted, for

Figure 1: Incorrect storage of batteries

[6] 'Developing Global Quality Standards for the Accreditation of PV Training Programs and the Certification of PV Practitioners' Knowledge and Skills Competencies', Fitzgerald, M., 28th IEEE Photovoltaic Specialists Conference, Anchorage, USA, 17-22 September 2000

example during system installation.

1. Ensure that the delivery of system components is made at the correct time, and that adequate storage is available to protect components once on site. (**C**)

2. Batteries should be shipped dry from the supplier if possible (with the electrolyte in a separate container). Equipment for filling batteries on site must also be provided. This will require that the batteries are given a forming charge after filling. If this is not possible on site, batteries must be filled before shipping, and precautions taken against spillage during transport. If batteries are stored containing electrolyte, periodic recharging will be necessary. Batteries should be stored indoors. (**C**)

3. Acceptance of components – all components should be visually inspected on delivery. This is particularly important for batteries, for which polarity should be checked and voltage measured to ensure the integrity of all internal connections. (**C**)

4.7 Quality control of system hardware

Documents to be provided at this stage: copies of certification for each component

It is not possible to achieve a high quality system if it is based on low quality components. Fortunately, the quality of components is one of the easiest aspects of a project to control because there are a number of appropriate international standards that can be used to ensure this.

1. For small projects of one or two PV systems, all system components should be checked individually on delivery. For large projects (i.e. many similar systems), a check on a representative percentage of system components selected at random should be made. The Quality Control procedures should be carried out by qualified staff, e.g. an accredited laboratory or individual trained by an accredited body[7]. (**C**)

2. When the PV systems are to be installed in large numbers and, in particular, when they are to be installed in remote locations, the components should be tested as a system, as they are designed to be installed. This PV system test should include the typical loads to be used on site. Note that the time to carry this out should be accounted for in the planning stage. Consideration should be given to setting up a trial system for testing and troubleshooting of problems. (**C**)

[7] For example, the Institute of Sustainable Power is establishing a global programme of accreditation for PV laboratories and training institutes, www.isp.org

3. Refer to international and national standards for guidance on stand-alone PV system design certification and tests[8]. (**C**)

4. Refer to standards for individual system components: charge controllers, inverters batteries etc. A number of relevant Task 3 documents also provide guidance on this subject (see Section 6). (**R**)

Figure 2: Acceptance testing of batteries

5. The PV module supplier can supply I-V curves for a sample or all modules – these can be used to check that modules meet specifications and also to group similar modules which minimises mismatch. (**R**)

6. The PV module supplier may offer a performance guarantee which specifies how much power the modules will generate under local weather conditions. This can be a useful mechanism for ensuring the quality of the equipment supplied. (**R**)

4.8 Installation

Documents to be provided at this stage: installation checklist

The highest quality equipment and best system design will not function correctly if it is badly installed.

1. Ensure that contractual responsibilities for installation are defined clearly, including warranty terms. Different scenarios are possible - the implementing organisation itself, a utility, an ESCO or an independent installer may be in charge of installation. (**C**)

Quality of Staff

To ensure high quality installation, the project manager should:

1. Assess the actual level of skill of the staff who will do the system installation. Request documentation to confirm these qualifications.

2. Depending upon the existing skill of the installers, ensure that there is adequate support and supervision from suitably qualified engineers.

Example 11: Uganda maintenance staff
The Case Study of PV water supply in Uganda (see Part 2) shows that, despite the PV training provided as part of the project, the local technicians were not able to carry out basic tasks such as using a screwdriver. An assessment of the skills level prior to the training would have avoided this problem.

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

2. Ensure competent and appropriately trained staff carry out this work[9]. Ensure that they are responsible for providing an initial acceptance test on the system installation. (**C**)

3. Ensure the installation is carried out in accordance with the specification, and that national and international standards are followed[10]. (**C**)

Figure 3: Poor system installation

4. A method statement should be prepared stating how the installation will be carried out, having due regard for any safety arrangements which must be made. This statement can be checked by an independent third party to ensure that the proposed procedures are appropriate. (**R**)

5. The battery terminals, fuses and electrolyte levels (where applicable) must be accessible for visual inspection and maintenance. (**R**)

6. Ensure that the termination boxes have a small hole at the lowest gravitational point to allow water and condensation to escape during the day - this hole must be covered with porous material to block entrance of insects. (**R**)

7. Ensure that cables are protected from the sun (UV resistance or conduit). (**R**)

4.9 Commissioning

Documents to be provided at this stage: commissioning check-list / test schedule, acceptance documentation

Correct commissioning of a system is crucial to ensure that it is functioning correctly before it enters into use. The documentation of this stage is very important because this will be the first point to refer back to if there are any problems with the operation of the system at a later stage.

1. The definition of responsibilities is particularly crucial at the commissioning stage. (**C**)

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[9] 'Developing Global Quality Standards for the Accreditation of PV Training Programs and the Certification of PV Practitioners' Knowledge and Skills Competencies', Fitzgerald, M., 28th IEEE Photovoltaic Specialists Conference, Anchorage, USA, 17-22 September 2000

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

Typical commissioning procedure – adapted from IEC PAS 62111

Acceptance process	Objective	Content of a suggested data sheet
Commissioning step 1: Evaluation of the conformity of the installed system with the accepted design	To check that the equipment complies to the contractual accepted design and any differences explained	Equipment list : Initial design list / as built list / comments
Commissioning step 2: Evaluation of qualification of the installation	To check that the system is ready to be operated	Letter
Commissioning step 3: Preliminary tests	To test that the system components operate correctly	Component by component verification: type and reference according to the system description Satisfactory installation : check list of key points Satisfactory operation: list of tests with targeted performances to be obtained
Commissioning step 4: Performance testing	To confirm the operating performance of the whole system	List of system tests with targeted performances to be obtained

2. The person responsible for the commissioning of each aspect of the system should be suitably qualified, to a recognised standard if possible. (**C**)

3. A schedule of appropriate functional tests should be designed, and signed off when all are completed satisfactorily. (**C**)

4. The person responsible for the commissioning of each aspect of the system should be required to confirm in writing that it has been satisfactorily commissioned, that all appropriate tests have been carried out and that results are satisfactory. (**C**)

5. Commissioning should be witnessed by an independent third party, if possible. This should be a PV expert. For larger projects, commissioning of a random sample of installations may be witnessed. Witnessing by the owner or user is also beneficial. (**R**)

6. The user should be asked to sign in order to indicate acceptance of the finished system where possible / relevant. (**C**)

7. A diagram should be provided, mounted in a clearly visible place, showing the system configuration and protection settings, the date of commissioning and contact details in case of faults with the system. (**R**)

4.10 Operation and maintenance

Documents to be provided at this stage: O&M manual, log book to record periodic measurements of the system.

Due consideration must be given to operation and maintenance. A system may be installed to the highest standards, but if it is not properly maintained there will be problems with its operation at a later stage. It is therefore important to ensure that sufficient budget is allocated for this purpose. The importance of regular system maintenance in order to ensure the medium to long-term sustainability of any project is often overlooked and cannot be stressed enough.

1. Responsibilities for operation and maintenance must be clearly defined. (**C**)

2. The system user / operator should be issued with a manual and / or comprehensive system documentation (in the appropriate language). This should include a circuit diagram (preferably in an easily understood format), information on how to operate the system and basic maintenance procedures. (**C**)

3. The supplier should provide access to documentation for system software, where applicable. (**C**)

4. The users must be instructed (in their training sessions) on the basic operation of the system and on how to remedy minor faults. A list of possible fault conditions requiring assistance of maintenance staff should be given to the users. The procedure for contacting maintenance staff should be established and communicated clearly to the users. (**C**)

5. Users should be involved in system operation, e.g. by checking battery voltage or water level. Users should be instructed on component replacement procedures and how they will know that components need to be replaced. This is particularly important for the battery - there should be a procedure which describes how to decide when it is necessary to change a battery. Instruction should be given on what to do with the battery / battery acid. (**C**)

Operation and Maintenance Issues

- It is vital to ensure that a person or organisation is identified who will take *long term* responsibility for O&M of the system.
- Ensure that the spare parts will be available over the entire project lifetime – the hardware supplier should be able to demonstrate long term commitment to the project.
- Users must be trained to make basic checks of the system, and to recognise when it needs to be serviced.
- An annual check by a technician is advisable to confirm that the system is functioning correctly.

6. Users should be trained in the appropriate management of all loads and informed about how to select suitable appliances which will not lead to poor system operation[11]. They should also be advised regarding efficient usage of the system, for example, matching demand to supply availability. (**C**)

7. An operational plan and system performance analysis should be conducted for at least two years after installation. (**R**)

[11] 'Use of Appliances in Autonomous PV Applications: Problems and Solutions', IEA Task 3, www.iea-pvps.org

8. A log book of maintenance schedule, maintenance completed and components replaced should be made and updated regularly. (**C**)

4.11 Guarantees

Documents to be provided at this stage: guarantees

A system would not be considered to be high quality unless the owner or user is offered a guarantee, both for the components and for the installation.

1. The planning team must assess the different guarantees for the components and identify who will be responsible for these guarantees. (**C**)

2. Guarantees for individual components should be in agreement with current international / national guidelines. (**C**)

3. Installation guarantees should be provided. The type of installation guarantee may be of three kinds:

    - "parts" guarantee;
    - "parts and labour" guarantee;
    - extended service guarantee "parts, labour, lead time to service". (**R**)

4. The procedure for reporting component failure and making use of guarantees should be clearly defined. The user’s ability to report faults should be considered and suitable mechanisms for reporting should be devised where necessary. If the user does not have the ability or means to make claims under the guarantee, any guarantee is effectively useless. (**C**)

5. A performance guarantee may be provided, which will stipulate a minimum number of energy units over a given time period. If the stated amount of energy provision is not reached, and assuming the user has not increased the load, then a penalty may be payable by the supplier. (**R**)

4.12 Safety

Documents to be provided at this stage: Relevant safety guidelines for the site(s) concerned.

Safety regulations are country specific and the project manager should always ensure familiarity with the regulations applicable in the project country.

1. In general, procedures should be in place to ensure that throughout the project all members of the team conform to safety regulations and show due regard for the health and safety of all other staff and the public. (**C**)

2. The design engineer must ensure that the system will not pose any hazard to the users. (**C**)

3. During installation of the system, the project manager must ensure that all installation staff are familiar with safety guidelines. The installation procedure should be checked for safety considerations. The project manager must ensure that suitable clothing and equipment are provided for the installation team. (**C**)

4. Once the system is in operation it is important that the system users are made aware of any potential hazards by the use of appropriate labelling. (**C**)

4.13 Post project evaluation and performance assessment

An essential part of any quality system is continuous improvement and learning from past projects. It is therefore recommended that a project evaluation is carried out after a substantial operational period when it is possible to make a realistic assessment of whether the system meets the user's requirements. It is also useful to ascertain whether the system meets the technical specifications and assess whether this is sufficient to ensure that the system user is satisfied.

1. An essential element of the post project evaluation is an assessment of the technical performance of the PV system. The overall system quality and hence long term performance can only be assessed by carrying out monitoring. Guidance on performance assessment is given in a separate Task 3 document – 'Performance assessment guidelines'. In addition there are a number of relevant IEC standards which address this topic[12]. (**C**)

2. There should be ongoing monitoring of the non-technical aspects of a project. Annual visits of a representative proportion of sites should be undertaken to ensure the continued operation of aspects such as:

Figure 4: Example of a safely installed battery

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

management of the service provided by the PV system, satisfactory O&M, continued training of project staff and adequate supplies of spare parts.

3. It is important to carry out a post project evaluation of the financial aspects of the project. In cases where the system was purchase on credit, with regular repayments, this is essential to ensure the financial sustainability of the project. (**C**)

4. Checks should be made of system utilisation/load growth. If the loads are shown to be increasing, there will need to be an upgrade to the PV system capacity. Alternatively, if this is not possible, the users must be re-educated regarding the permitted loads. (**C**)

5. User satisfaction with the system should be assessed by means of a suitable questionnaire. This may be conducted individually, at a workshop, or by mail, depending upon the nature of the project.

5 CONCLUSIONS

The PV industry is growing rapidly. Stand-alone PV has enormous potential for applications in remote locations all over the world. Unless we focus efforts on introduction of quality now, the systems installed will fail and confidence in the performance of stand-alone PV will be severely damaged. This will affect market growth significantly.

Quality management and quality control are required in the implementation of every project to ensure 100 % success every time. The introduction of quality procedures to every industry means that such standards will soon be universally required. Stand-alone PV systems require quality management more than many other engineering applications, largely due to the remote locations and the users' dependence upon them.

As the user is frequently more involved with a stand-alone PV system than in most other energy projects, it is vitally important that the user receives tailored training in the main aspects of system operation, load management and basic maintenance issues.

6 BIBLIOGRAPHY OF OTHER TASK 3 DOCUMENTS

The following guidelines and publications have been written by Task 3 experts. These documents, or information on how to obtain these documents, may be found on the PVPS web-site: www.iea-pvps.org.

- Examples of Stand-alone PV Systems
- Survey of Stand-alone Photovoltaic Applications in Developing Countries
- Battery Guide for Small Stand-alone Photovoltaic Systems
- Stand-alone Photovoltaic Applications - Lessons Learned
- Recommended Practices for Charge Controllers
- Survey of National and International Standards, Guidelines & QA Procedures for Stand-alone PV Systems
- Use of Appliances in Autonomous PV Applications: Problems and Solutions
- Management of Lead-acid Batteries used in Stand-alone Photovoltaic Power Systems
- Testing of Lead-acid Batteries used in Stand-alone Photovoltaic Power Systems – Guidelines
- Selecting Stand-alone Photovoltaic systems – Guidelines
- Monitoring Stand-alone Photovoltaic systems: Methodology and Equipment – Recommended Practices
- Protection against the Effects of Lightning on stand-alone Photovoltaic Systems - Common Practices
- Demand side management for Stand-alone Photovoltaic systems
- Selecting Lead-acid Batteries used in Stand-alone Photovoltaic Power Systems – Guidelines
- Alternative to Lead-acid Batteries in Stand-alone Photovoltaic Systems

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