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TRAINING MANUAL FOR DOMESTIC SOLAR ELECTRICITY TRAINERS

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TRAINING MANUAL
FOR
DOMESTIC SOLAR ELECTRICITY
TRAINERS

Written by Jean-Paul Louineau, Alliance Soleil Sarl

(**VERSION** : JUNE 2009)

Special thanks to all trainees,

solar technician trainees for their input.

Table of Content

The 12 MODULES OF THE TRAINER'S MANUAL

MODULE 1: Introduction for trainers

1 Manual generalities

This manual is a key element in a series of training materials which have been developed with the financial support of ETC Energy/TTP. It is the fruit of many years of experience in the training of technicians and trainers in solar energy; experience acquired by its author, Jean-Paul Louineau, with organizations such as URDT in Uganda, SSD Yeelen Kura in Mali, and BIOSOL of ASRAMES in the Democratic Republic of Congo. All of this work would not have been possible without the continued support and confidence of Willeke Parmentier, coordinator ETC Energy/TTP since 1998.

This English version (January 2009) is an updated version of the original French version which was produced in January 2006.

This manual is a reference document for trainers which will enable them to carry out a complete training course on the techniques of domestic solar system sizing, installation and maintenance.

2 Target groups

2.1 Trainers and technical Institutes / vocational schools

This manual is intended for use by vocational technical school teachers, secondary school teachers and for professional trainers of solar entrepreneurs or NGOs who work with rural electrification programmes.

2.2 Students / trainees

The training programme content is designed for:

- Students at vocational technical schools preparing a professional diploma in electricity or mechanics;
- Independent solar technicians with sound experience in the installation of domestic solar systems, but with no prior knowledge of how to size or maintain such solar systems;
- Technicians, employed by solar businesses (suppliers or solar service providers) or NGOs, who need to improve their overall knowledge of sizing, installation, maintenance and servicing of domestic solar systems.

3 Objective of the manual

The manual outlines a complete course in the sizing, installation, and maintenance of domestic solar systems and in the training of technicians in these subjects.

The basic objective is to:

Train and Qualify

Entrepreneurial technicians (technicians with a business sense),

rather than simple installation technicians.

The course enables trainers to ensure that trainees acquire the following skills and competences:

Proficiency	**Details of course content**
Knowledge of the components and functioning of a domestic solar system Knowledge of advantages and limits of domestic solar systems	Principal characteristics of each component and detailed description of system functioning Description of weak points of the system (ex: regulator/battery)
Basic sizing of a domestic solar system	Sizing based on the energy needs of the customer (loads, duration of use), weather data (energy production of the PV modules) Component selection according to availability on local / national markets
Price Quotations	Concepts of purchase price vs. sale price, labour and transport costs, profit margins (quality / price ratio)
Installation of a domestic solar system	Installation of all components according to a rigorous code of practice (from the choice of the orientation of the PV modules, to the placement of lamps and the fastening of cables)
User training	Techniques and information for the training of system users (daily use, respecting the system indicators and instructions, routine maintenance tasks)
Maintenance of a domestic solar system	Guidelines for the maintenance of system components, including evaluating the behaviour of the user and his/her ongoing training. Minor repairs
Concepts of entrepreneurship / Commercial aspects of solar businesses	Communication in-country or locally, marketing, management, innovation, services to customers (after sales). Keeping up to date with new technologies

4 Basic training materials

The following is a list of the materials needed to carry out a training programme:

Designation	Description	Purpose	Target
1. **Trainer manual :** *"Domestic Solar System" trainer Manual*	**12 modules (**format A4): this document	Curriculum for trainers (including practical exercises, training techniques, lists of necessary equipment)	Trainers
2. **Handbook:** A practical guide to solar photovoltaic systems for technicians (also called '**Paper Tool**')	English version : 99 pages, format A5, (ISBN 978 1 85339 659, 2008, J.P.Louineau)	A reference handbook for technicians and a teaching handbook	Solar technicians and trainees
3. **Strategies and Examinations for trainer qualification**	Contains practical and theoretical examinations ready-made	To allow experienced technicians to become qualified trainers	Experienced technicians experienced trainers
4. **Teaching videos**			
Video : *Installation of Small Solar Systems*	CD Rom, 23 minutes (August 2002, J.P.Louineau)	Illustration of installation techniques	Trainers and trainees
Video : *Operation and User Maintenance of Small Solar Systems*	Same CD as above, 19 minutes (April 1999, J.P.Louineau)	Introduction to solar systems as seen by the system user	Trainers, trainees, solar system users or potential clients
5. **Equipment lists and methods** (proposed at the end of this module)	Solar equipment, electricians' tools, measurement equipment, teaching materials	To conduct the training sessions and practical exercises	Trainer

4.1 Training manual

This training manual is an expanded version of the book **A Practical Guide to Solar Photovoltaic Systems for Technicians, Sizing, Installation and Maintenance**, also referred to as the '**Paper tool**'.

Each Module in this manual corresponds to a chapter in the Paper Tool as follows:

Module	Module name	Corresponding chapter of the Paper tool
1	Introduction for trainers	-
2	Units of measure and basic formulae for electricity and energy	2
3	Introduction to small solar photovoltaic systems	3
4	The client : meeting his or her needs	4
5	Photovoltaic modules	5
6	Charge regulator	6
7	Batteries	7
8	Loads, inverters, cables and main accessories	8, 9
9	Sizing and Price Quotations	4
10	Installation of solar systems	11
11	Maintenance and servicing of small solar systems	12,13
12	After-sales service, tools	13,14

The Modules should be taught in order. However it may be a good idea to teach Module 7 before Module 6.

Each module is structured as follows:

	Chapter	Comments
1	**Objectives**	Outline of the main study topics and learning objectives
2	**Module duration**	Suggested duration of teaching in hours
3	**Necessary teaching equipment**	List of the materials needed to carry out the module
4	**Module content**	Curriculum: information to be taught about the given subject with practical exercises
5	**Summary diagram**	Synthetic diagram which summarises the module content onto one page
5 (or 6)	**Evaluation and feedback**	Evaluation of the trainees' skills

☞ Each module proposes theoretical exercises (on the use of formulae) and practical exercises to give to the trainees either during the course, or as evening/home work.

☞ The answers to all exercises are provided in each module.

☞ Some information is repeated in several modules; this is to give emphasis to key skills or concepts.

4.2 The Paper Tool

The book **A Practical Guide to Solar Photovoltaic Systems for Technicians, Sizing, Installation and Maintenance** is also known as the 'Paper Tool' in the context of these training documents. The Paper Tool was developed to accompany a technician from his or her workshop/enterprise into the field during system installations and maintenance visits. Its structure also allows it to be used as a teaching tool in training programmes. The Paper Tool contains useful recommendations and procedures for:

- the assessment of customers' energy needs;
- system sizing and choice of quality equipment;
- installation, maintenance and reparation of systems;
- after-sales service and user training.

It also contains a complete glossary of all technical terms and a bibliography of books and internet sites.

4.3 Strategies and examinations for trainer qualification

This document proposes a strategy and standard examinations to qualify participants having received one or more training.

There are 4 levels of qualification:

1. **Installer of solar home systems** **(IST)**
2. **Maintenance and repairs solar technician** **(MRST)**
3. **Design solar technician** **(DST)**
4. **Trainer of solar technicians** **(TST)**

4.4 Training videos

These videos illustrate some parts of the course. The contents are listed here:

Video : *Installation of Small Solar Systems*

Topic	Duration (mn)
Introduction	00.0 – 2.34
What is the Installation of a Small Solar System?	2.34 – 3.20
What is a small solar system?	3.20 - 5.45
Methodology of Installation	5.45 – 6.20
Preparation for Installation	6.20 – 10.38
Solar Module Installation	10.38 – 12.45
Regulator Installation	12.45 – 13.20
Battery Installation	13.20 – 16.40
Load and Cable Installation Hints	16.40 – 18.58
The Finishing Touches for Servicing	18.58- 22.08

Video : *Operation and User Maintenance of Small Solar Systems*

Topic	Duration (mn)
Introduction	00.0 – 2.11
Why use Small Solar Systems?	2.11 – 3.06
What is a Small Solar System?	3.06 – 6.22
Main advantages of a Small Solar System	6.22 – 7.30
Limitations of a Small Solar System	7.30 – 8.15
How Best to operate a Small Solar System	8.15 – 10.52
How best to maintain your system	10.52 – 14.14
Safety and Environment Issues	14.14 – 15.10
Closing remarks	15.10 – 15.31

5 Solar training courses for solar businesses or NGO technicians

5.1 Educational level required

The education level required to assimilate the theories and practices in this training course is equivalent to that which is necessary for obtaining a professional diploma (certificate of aptitude) of electrician / or mechanic – or a higher level in these fields of study.

5.2 Planning the duration of training courses

The curriculum content in each module is, in general, rather short. So the length of a training course and the individual modules within it depend of the following factors;

☞ *The specific audience in the training session* – installers of systems, maintenance & repairs solar technicians or design solar technicians – or general logisticians

☞ *The educational level or prior experience of the participants in the group.* Participants with prior experience in electrical installations or solar systems will of course assimilate the course content more easily. The greatest planning difficulty arises when a group has several different levels to teach to.

☞ *Individual module duration may vary between 2 and 15 hours* per module depending on the emphasis that is placed on it and the time allocated to practical exercises.

- A three day training course would be the minimal time need to cover the entire curriculum (a theoretical overview without any practical exercises).
- A two week training course (10-12 days) would allow for a sound theoretical course of study and some practical exercises.
- A three week training course (15 – 18 days) would allow for a sound theoretical course of study backed up by extensive practical exercises to reinforce the trainee's fieldwork capacity.
- It is also possible to carry out training courses using only one or a few of the modules to meet specific needs of individual trainees or groups.

Module	Module name	Estimated time needed (hours)	Minimum time needed for complete training (hours)
1	Introduction for trainers	-	-
2	Units of measure and basic formulae for electricity and energy	2 to 6	4
3	Introduction to small solar photovoltaic systems	2 to 4	3
4	The client : meeting his or her needs	6 to 10	6
5	Photovoltaic modules	8 to 10	8
6	Charge regulator	4 to 6	4
7	Batteries	6 to 8	6
8	Loads, inverters, cables and accessories	4 to 8	4
9	Sizing and price quotations	8 à 12	10
10	Installation of solar systems	10 to 15	10
11	Maintenance and servicing of small solar systems	6 to 10	6
12	After-sales service, tools	2 to 4	2
	Total		63

6 Solar training in vocational technical or secondary schools

6.1 General level required --- target groups

This training course curriculum can be used in vocational technical and secondary schools. The level required to assimilate the theories and practices in this training course is equivalent what is necessary for obtaining a professional diploma (Certificate of aptitude) of electrician or mechanic (a 2 to 3 year course of study after secondary school). When used in secondary schools, the course may be used at its most basic level in basic science courses.

6.2 Training method: traditional or modular

Generally, there are two methods of teaching in vocational technical schools: traditional training and modular training.

- Traditional training: consists of the teaching of 'traditional' subject matters such as mathematics, languages, electronics, mechanical drawing, drafting, mechanics, etc. A certificate of aptitude or diploma is issued at the end of the course of study based on the results of theoretical and practical examinations.

  Such a course of study ranges from two to three years depending on the country. The number of course hours is between 2200 and 3300 for the entire curriculum (based on 35 hours per week and 32 weeks per year).

- Modular training: is a programme of study organised around the specific proficiencies needed for a given job, such as an electrician – assembler. The proficiencies include job-specific skills as well as more general skills. Each subject, or target proficiency, is taught in a module. Examples of modules for an electrician would be; use of measurement devices, maintenance and repair of electric systems, analysis of direct current circuits, etc.

  Students study the modules over a two to three year course of study, passing from one module to the next and obtaining a diploma or professional aptitude certificate at the end of the full course. There is some flexibility in the order in which the modules can be studied, but it may be necessary to pass certain modules before advancing to other subjects.

6.3 Suggestions for integrating solar training into 'traditional' training curricula

The following table gives an indication of the time in number of course hours that would be needed to add to an existing electrician's curriculum, the topic of 'domestic photovoltaic systems'.

Existing courses	Existing subject matter (useful for solar systems)	New topics to introduce	Extra required time (Hours) distributed over 1 to 3 years
Mechanical drawing	Technical drawings of mechanical operations from all angles	Drawing of mounting structures of solar modules (e.g. on roofs or poles)	5
Technology	Components of electric systems (batteries, lighting, wiring)	Components of PV systems (solar modules, regulator, batteries (lifespan / depth of discharge)	20
Electrical Drawing	Charts of electric components of systems	Symbols of PV modules, inverters, regulators	1
Electronics	DC current, AC current, power, energy, output, consumption, cables sizing (voltage drop) and electric protection sizing	Concepts of sizing (energy consumption by loads = energy produced by PV modules)	5
Practical training	Using multimeters, system wiring (simple lighting, two-way switches, plug, shunt, protection) Installation, maintenance and breakdown services	PV generator wiring (modules, regulator, battery) PV generator servicing	30
'Entrepreneurship' course (Business)	Nil	Description of a service company in rural areas, marketing, organization	5
Work placement	On the job training sessions	On the job training sessions	0
Evaluation/ examination	Nil	Theoretical and practical examinations	8
		Total	74

So for example, it would be necessary to add 5 more hours of course work to incorporate domestic solar systems to an existing electronics course. Overall it would be necessary to add 74 hours to a complete training programme.

6.4 Suggestions for integrating solar training into 'modular' training courses

In modular training programmes, the subject of 'domestic solar systems' may be added as another module to an existing course of study. It could be named: `Domestic photovoltaic solar systems' (comprised of 12 small modules).

This manual includes all the elements necessary to create such a module.

7 Initiation to teaching techniques

7.1 Basic principles

The techniques of training (technical teaching) suggested here are based on the experiences of the author, gathered from many years of carrying out training sessions[1]. The suggested methodology for facilitating and animating this training programme is based on these following principles:

- ☑ Each participant has his or her own preferred way of learning.
- ☑ Trainees learn better when they are in a relaxed state; when learning is a pleasure and not a stress.
- ☑ Emotions play an essential role in learning; as a source of energy and motivation, they facilitate long term memory.
- ☑ The trainer(s) and the trainees have a large range of knowledge and experiences to be shared. All must cooperate in this sharing.
- ☑ Programme content should be agreed between trainers and participants, not imposed.
- ☑ Training methods are custom-made and flexible at all times.
- ☑ Practical exercises make up at least 50% of the training activities.
- ☑ Making mistakes is an integral part of learning.
- ☑ Mutual respect for all participants is necessary at all times.

It is strongly advised to adhere to these principles, before and during training sessions.

What I hear once, I forget;
What I see, I remember;
What I do is what I know.

(Educational poster in schools in South Africa 1999 -2000)

[1] And also from advice found in the excellent book ‘Former sans ennuyer’, author Bernard Hourst, 2002. Code ISBN 2-7081-2757-8, Organisation Editions, 1, rue Thénard, 75240 Paris Cedex 5.

7.2 Important qualities of a training session

	Comments
1. Content value	➲ Trainees feel that their time is well invested, that what they learn is directly related to their work and also on a personal level.
2. Clarity	➲ Trainees understand the level of importance attached to each subject matter, for example understanding installation procedures is more important than understanding the internal functioning of a battery.
3. Flexibility	➲ Training is adapted to best meet the needs of the trainees. This supposes that the experience / educational levels of the trainees are well known. This should be evaluated at the beginning of the training session.
4. Well structured	➲ A training session that is too rigid risks being boring and `one way'. A poorly structured training session may seem disorganized, and can lead the trainees to doubt about the seriousness of the training or the trainer.
5. Rhythm	➲ All trainees have limited attention spans (20 minute cycles on average). It is necessary remember this in order not to drown them in new information, with the risk of discouraging them.
6. Facilitate memorization	➲ It is essential to ensure that theoretical knowledge is backed up with understanding from practical exercises.
7. Facilitate understanding	➲ Presenting information in levels of complexity often proves to be effective. For example, explain the functioning of each component of a solar system, then the interaction between two components, and then between all the components as a whole system.
8. Be realistic	➲ It is not possible to transform trainees into full solar technicians after 5 days of training. The objectives of the training session should be defined at the beginning of the session and held to during the course.
9. Encourage practical work and autonomy	➲ Because training must lead to the use of transmitted information, this information must be applied <u>during</u> the training session. You must avoid saying *`we do not have time now to work on this field procedure; we will do this later ...'*. Such a trainer does not present a role model who encourages trainees to put into action what they are learning.

7.3 Important qualities of a trainer

The trainer must have, or strive to develop, the following qualities:

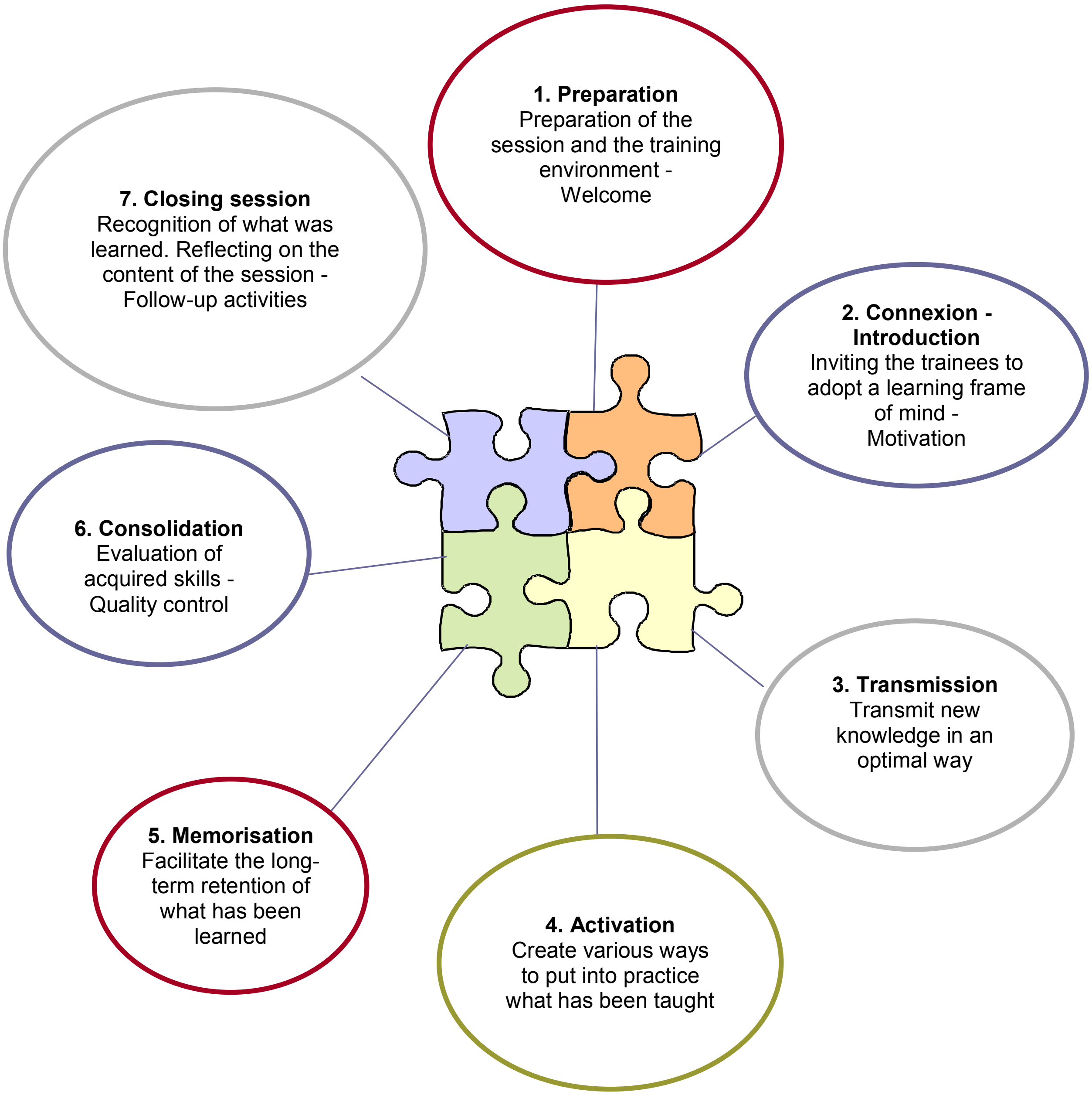
Quality	*Comments*
1. Passion and command of the subject	➲ The trainer believes in what he or she says; the subject has value for him or her.
2. Energy, joy, and a positive attitude	➲ A dynamic voice and enthusiastic gestures and anecdotes help trainees to remain attentive.
3. Sound organisational skills for clear, effective and captivating training sessions	➲ Meticulous preparation allows the trainer to easily adapt to trainees' needs.
4. Well developed sense of authority	➲ The trainer must demonstrate coherence between what he or she says and what he or she does. His or her credibility inspires respect.
5. Humility and respect for oneself and others	➲ A trainer cannot pretend to know everything, but can assist trainees to seek solutions to questions.
6. Balance between self-confidence and confidence in others	➲ A trainer is very experienced and seeks to transmit his or her experiences to the trainees, increasing their self-confidence.
7. Comprehension of the psychology of individuals and groups	➲ A trainer must evaluate the behaviour of individuals, and their participation in the dynamics of the group. No trainee should be overlooked.
8. Comprehension of group dynamics	➲ A trainer must be able to take the pulse of the group in order to detect any negative factors which can impair learning or create stresses in the group.
9. Capacity to explain clearly	➲ A trainer must use his or her imagination to present the subjects from different perspectives which speak to the trainees' experiences.
10. A good sense of humour and theatrics	➲ Humour reinforces links with the participants and facilitates learning. ➲ A trainer controls the volume, speed and intensity of his or her voice according to circumstances. He or she creates emotion!

Of course it is difficult to master all the qualities mentioned here, but to be aware of them is essential to acquiring them in due course. In any case, it is **absolutely necessary to avoid:**

- ☒ Giving the impression that you have not prepared a session.
- ☒ Being satisfied with unsatisfactory answers to questions.
- ☒ Being out of touch with developments in your field.
- ☒ Not keeping to planned schedules or unable to finish modules on time.
- ☒ Not involving the trainees.
- ☒ Not establishing personal links with the trainees and / or the group.
- ☒ Using sexist or racist comments, or inappropriate humour.

7.4 Training structure: training cycle

Ideally, a training session flows through the following 7 stages.



The **7 phases** are represented as a puzzle, demonstrating the interaction between the phases to make a successful training course.

These phases are not always carried out in chronological order. For example, the **preparation phase** is intense at the beginning of the training course, but also throughout as minor adjustments may need to be made on a daily basis (it may be necessary to adapt the rhythm of the programme according to what the trainees can absorb). In the same way, `Transmission' is a daily activity, except on the last day of the course, reserved for consolidation and or closure.

7.4.1 Training preparation

Before the beginning of a training course, it is necessary to carry out the following steps:

1. Define and clarify the objectives of the training course.

2. Gather information about the group (education and experience levels, weaknesses, expectations, levels of motivation).

3. Establish ways to evaluate the trainees in order to measure if the objectives of the training course will be achieved (see box below).

4. Assess the available resources for the different sessions (trainers, materials, timeframe).

5. Read and study attentively all the teaching materials. Practice yourself the planned exercises and check your results, before reproducing them in class.

6. Prepare a basic training course programme proposal.

7. Inform the organisers of the training sessions and training course as soon as possible. All the programme details should be communicated to the participating organisations along with a questionnaire for the participants to fill out.

8. Prepare a detailed training course programme, based on the feedback received about the level of the participants. This course programme is prepared with this Trainer manual and the Paper Tool.

9. Prepare all supporting materials to illustrate the various theoretical and practical exercises. These may be formulae charts, posters, diagrams, etc.

10. Organise the practical logistics; the classrooms or laboratories, the technical material, white or black boards, flipcharts, pens, etc. (see the last section **of this module**).

Select and prepare the classroom. Make sure that it is:

- Fitted with double the amount of seats necessary so each trainee can spread out his or her work;
- Well lit, quiet and without echoes, clean and well ordered;
- Comfortable: with fans or windows for fresh air;
- Equipped with white or blackboards for writing and hanging posters;
- Decorated with posters (ex : happy customers smiling);
- Equipped with running water for tea breaks;
- Equipped with an electricity supply (for running computers, TVs, music for relaxation).

HINT : PRE-TEST and POST-TEST

- It is very productive to give the trainees an evaluation at the beginning and at the end of the training session. The same test may be used for both purposes. At the beginning, the evaluation allows the trainer to assess the technical levels of the trainees; and for the trainees themselves, it gives them a good idea of the overall content to come in the session. It indicates the gaps to fill.
- These evaluations are of course not graded. At the end of the training programme, participants will be well aware of their progress.

Training for a qualification or certificate - Evaluation

- If the objective of the training session is to qualify technicians for a specific level or trainer status, refer to the document entitled: `**Strategy and examinations : qualifications for technicians and trainers**

Beginning the training

Welcoming the trainees is a crucial step on the first day, but every day thereafter as well.

Daily preparation of the trainer:

Physically		*Mentally (to fill up with energy, concentration and pleasure)*
Take care of your appearance: clothes, hairstyle, cleanliness		**Take deep breaths to relax yourself**
Put on a relaxed face, with a trusting and cordial smile	☺	**`Make a mental film' of the session to come, imagining the most details as possible: the first hour, the first day- this helps to be prepared**
Your voice should be clear		**Familiarise yourself with the names of the trainees before meeting them**

The first day will set the tone for the following days. It is necessary to:

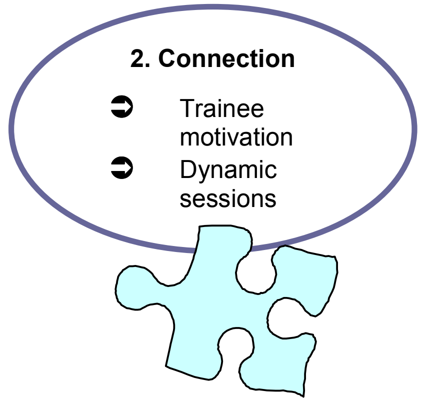
- Give a cordial welcome (smile, handshake).
- Introduce yourself as the trainer, giving some background information about yourself.
- Ice breaker - an activity to help the trainees to get acquainted and relax (introductions around the table starting with the youngest to the oldest or vice versa (or similar game), expressing the expectations of the participants.
- Explain the practical aspects of the training course: daily schedule, meals, breaks, evening work to be carried out, and any logistic information to be given to the trainees.
- Draw a table of trainee expectations by inviting them to share with the group (make a poster of these and display it in the room).
- Distribute the 'Paper Tool' at the beginning of the training course.
- Do at least one practical exercise the first day.

Be aware of the emotional and social dynamics in the group

In addition to creating an ideal 'physical' environment, it is necessary to attempt to create a quality emotional and social environment.

- Encourage the self-confidence of each trainee.
- Use positive language (there are no problems, there are only challenges to be met).
- Listen to the participants (their fears and anguishes about not succeeding or understanding).
- Leave some space for humour and imagination: we can learn very seriously and yet enjoy the process.
- Make yourself available and accessible for those trainees who may not wish to speak in front of the group.

7.4.2 Connection “Switching On”



It is important to establish a connection with the trainees – to incite motivation for learning the subject matter.
Incite the desire to learn – Incite learning

It is thus necessary to know how to motivate the group (to ensure connection) and to know how to identify when motivation is lacking (disconnection – trainees switched off).

How to incite and maintain motivation?

Techniques	*Comments*
1. Make a success of the introduction to the overall or daily session	➲ Example : tell a history, a striking anecdote on the relevance of solar systems in rural areas ➲ Example : explain that understanding the morning topic is essential to wiring solar systems in the afternoon session
2. Present the future benefits of the training	➲ Example : explain that the knowledge of maintenance procedures will allow the participants to acquire a notoriety among professional colleagues
3. Make the beginning easy	➲ To increase the confidence of the participants, start off by asking easy questions and congratulate good answers.
4. Ensure that the course content is appropriate for the level of the group	➲ Course content that does not challenge the trainees enough will frustrate them. Course content that is too difficult for the group will discourage them.
5. Remember that all trainees do not absorb information at the same rate	➲ Give additional work to those who understand quickly
6. Maintain a low level of stress – put trainees at ease	➲ Encourage and congratulate positive efforts
7. Support team activities	➲ Organise practical exercises in small groups
8. Measure the level of attention and comprehension	➲ By asking questions frequently
9. Indicate progress levels achieved with designated indicators or ‘anchoring points'[2]	➲ With simple tests, games or by the creation of posters by the trainees
10. Encourage interaction between trainees and between the trainees and trainer(s)	➲ Make frequent breaks; this allows the promotion and assessment of cohesion within the group.

[2] An ‘anchoring point’ is an indicator showing a certain level of skill (for example the difference between “no-load voltage” and “voltage under load”).

Identify "disconnection" – when trainees lose interest or switch off

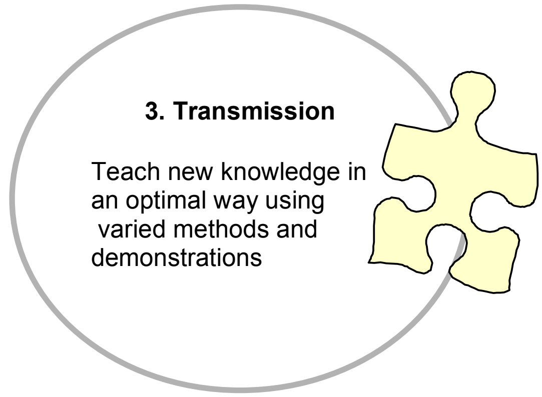
It is quite easy to observe the participants and measure if anyone is disconnected.

Indicators	☞	*Action to take*
Confusion about a given exercise	☞	**Simplify the current activity**
Difficulty to concentrate	☞	**Change the rhythm of the lesson or activity**
Lack of energy	☞	**Have a break or tell a true story/ anecdote about fieldwork – or other relevant experiences**
Boredom, lethargy	☞	**Change the topic, or tackle the subject from a different angle (for example move into practical application exercises and return to theory later)**
Difficulty to express oneself or to take decisions	☞	**Restart the subject at the point where the trainees can express clearly what they have learned (in the form of role play or revision)** **This will be the `anchoring point' for the next session**

Trainees will switch off for many reasons such as lack of water, of food, physical exercise, or sleep; but also from excesses (too much food, noise, emotional stress). But too often, trainees switch off because of the trainer who may be:

- Annoying; the participants are bored,
- Speaking with a monotonous voice and sitting in a chair all the time; the participants fall asleep,
- Speaking too quickly or with too much information at once; the trainees cannot understand,
- Skipping continually from one subject to another; the trainees are in total confusion,
- Unclear; not answering questions clearly and to the point.

7.4.3 Transmission



Each person has a preferred way of learning. For example some learn better by listening, others through practical demonstrations, and some prefer reading information in a document.

Hence, it is necessary to teach in various ways.

Methods for transmitting information

In addition to the 'traditional' teaching method of standing in front of a group of participants/trainees and presenting a lesson, there are several other methods that can be used in training sessions.

Method	*Illustrations / comments*
1. Reading	➲ To be avoided whenever possible. However, in some cases, reading short extracts is very effective.
2. Theatre	➲ Role plays where the participants put themselves in real-life situations (for example technicians and customers, etc.).
3. Diagrams / drawings	➲ A drawing or an electric diagram can often explain an idea better than lengthy oral explanations.
4. Stories	➲ Share your own practical experiences with solar systems, anecdotes from the field.
5. Summary Diagram	➲ Summarize onto one poster the lesson learned. See examples in sections 5 of modules 2, 3, 4, 5 and 6.
6. Practical exercises / experiments	➲ Prepared by the trainer or the participants to demonstrate a given phenomenon.
7. Games	➲ \`Questions for a solar champion'. Games on videos sequences: \`look for the error in a solar installation or in the behaviour of a technician with a customer'.

Creative diagrams or small drawings
are better than lengthy speeches!

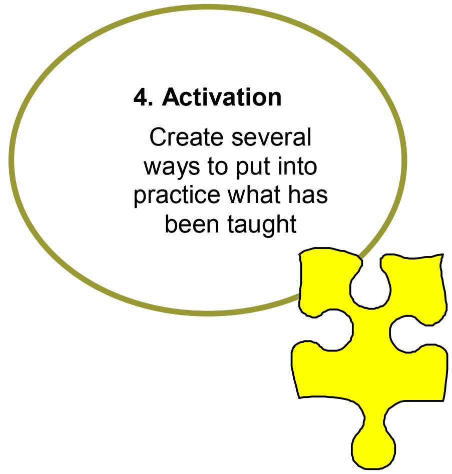
Fundamentals of transmitting knowledge

1. Principle of multitude beginnings and endings	➲ It has been proven that we learn better at the beginning and the end of a given session. It is thus necessary to multiply the number of beginnings and endings by creating many short sessions (average 20 minutes) rather than fewer long sessions. It is important to conclude each session well.
2. Be sure of the quality of information transmitted	➲ The information you provide must be: credible, useful, updated, precise and acceptable by all (distinguish clearly between facts and opinions).
3. Good coherence between verbal language and body language	➲ Take time to think before speaking, be aware of the movements of your own body and control your voice. According to communication specialists, transmitted communications are received as follows: - 7 % from the words used, - 38 % from our voice, - 55 % from our corporal (body) language. **This means that trainees receive a great deal of information that is not spoken verbally.**
4. Principle of a sound foundation (or of layers)	➲ Introduce new information with gradually increasing complexity, like building layer upon layer.

Table: teaching example according to the principle of the layers

Layers	*New knowledge*	*Activities*
1st layer:	A solar module produces electricity by direct conversion of the light. Without light, there is no current production.	Put a module out in the sun and measure the current. Put the module in a black box, measure the current. Draw conclusions
2nd layer	The sun irradiation is maximal at midday and when the sky is clear, without clouds. It is approximately 1000 W/m^2	Information given in a lecture
3rd layer	The solar module produces its maximum current when the sun irradiation is 1000 W/m^2.	Each hour, measure the current produced by a module beginning in the morning until the evening.
4th layer	The maximum current is noted `short-circuit current' or Isc. Isc depends also on the temperature of the module, the cleanliness of the module and any shadows on the module.	Have the trainees read the specification sheet of a module where Isc is indicated. Measure Isc with a dirty module, a clean module, with and without shade.

7.4.4 Activation



This phase is fundamental because generally speaking, it is estimated that in a given trainee group:

- 70% of trainees will not fully understand new information unless it is applied during the training.
- Information will be committed to long-term memory only if:
  - It is reiterated at least 3 times.
  - It is reiterated in 3 different ways.

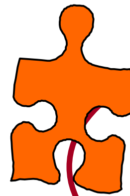
Basic principles:

1. Decentralise	➲ The trainer is no longer the central focus of the learning process. The trainees, either individually or in groups, become the central focus of activity – with the trainer on the periphery providing supervision and guidance. The trainer remains always present and active.
2. 50 % of the time	➲ Practical exercises should account for at least 50 % of the time allotted to the training programme. Warning: practical exercises can drag on however if they are not properly organized (leaving no time for other subjects).
3. Preparation	➲ Before a given session, the trainer must have carried out the practical exercise him or herself to know its duration and the conclusions.
4. Steady rhythm	➲ Activation time for practical exercises must have a steady rhythm.
5. Quality of results	➲ The result of "activation" time must be clear and for everyone. Confused and unexplained results will confuse the trainees.

Activation examples (individually or in small groups)

♦	Research a specified piece of information or data from manufacturer data, manuals or textbooks
♦	Practice calculations using the energy formulae learned, system sizing exercises, making electric diagram drawings
♦	Create a poster to illustrate a given concept or formula or sizing exercise, diagram
♦	Make practical exercises for: installation according to set procedures, measurements of electric consumption, trouble shooting exercises
♦	Games : "Questions/Answers", "Find the error", "Questions for a Champion"

7.4.5 Memorization phase



5. Memorization

Facilitate the long-term retention of what has been learned

In general, most of what is learned today will be forgotten in 24 hours, unless there is a voluntary approach to consolidate this information in our "long term" memory.

Basic techniques

1. Monitor the atmosphere of the sessions	➲ Promote an atmosphere of concentrated relaxation for trainees using humour and imagination and leaving a margin for error. Stress has a blocking effect on memory retention.
2. Don't speak too quickly	➲ Adapt the speed of your voice to the difficulty of the subject (a slow deliberate voice for a formula to be memorized, a quick lively voice to tell a joke).
3. Regular reminders of what was learned	➲ Giving reminders : 10 / 48 / 7 rule - After 10 minutes, - In 48 hours, - After 7 days.
4. Create many short breaks	➲ These are not full "tea breaks", but rather small pauses during which trainees can stretch, stand up or reorganise their notes (the trainer too).
5. Leave time between two concepts	➲ Allow enough time between subjects for participants to take notes.
6. Encourage trainees to repeat what they have just learned	➲ By using their own words and phrases, trainees internalise the information and concepts learned.
7. Take care of the teaching materials	➲ Present posters well with the principal notion in the centre, well outlined. Post all the posters around the room for future reference. These will help notions to sink in (training without effort). ➲ Play on words or songs. ➲ Create the ten commands of the solar technician.

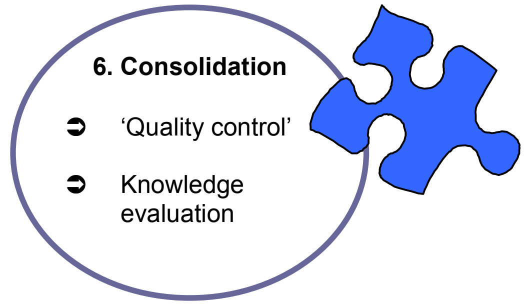
Advice for the design of posters

- *Are the fundamental ideas expressed?*
- *Are the ideas in a logical order?*
- *Are the colours well selected?*

Advice for writing or drawing posters

- *Not more than 7 words per line*
- *Not more than 7 lines per poster*
- *Short texts, one idea per sentence or phrase*

7.4.6 Consolidation phase : Quality control



This phase tests what the trainees have learned by evaluating their skill levels. It is also a recognition of the proficiencies learned which reinforces self confidence.

Check the quality of what is being learned

To ensure learning:

1. Identify as soon as possible any misunderstanding	➲ Correcting misunderstandings is more difficult than teaching a new concept.
2. Recognize when things have been well learned **Clearly demonstrate progress indicators**	➲ This will give confidence to the trainees and motivate them to proceed. ➲ Trainees can measure their own levels of understanding (by filling in the "Table of expectations" expressed as a percentage of skills learned).

Knowledge evaluation

1. Use various forms of evaluation throughout the training course	➲ Tests or examinations can be individual or in small groups; theoretical or practical, role plays or field installations.
2. Homework	➲ Extra evening exercises facilitate the memorisation of knowledge and can be done individually or in small groups. ➲ The proposed work must be short and stimulating, in order not to spoil the pleasure of learning.

Testing principles for proficiency evaluation

A test or examination should be perceived as a check point on the road to guaranteed success. Let us remember a child learning to walk…she falls, gets up, falls again… but eventually she will walk, and later run! We don't punish children learning to walk, we encourage them every step of the way!

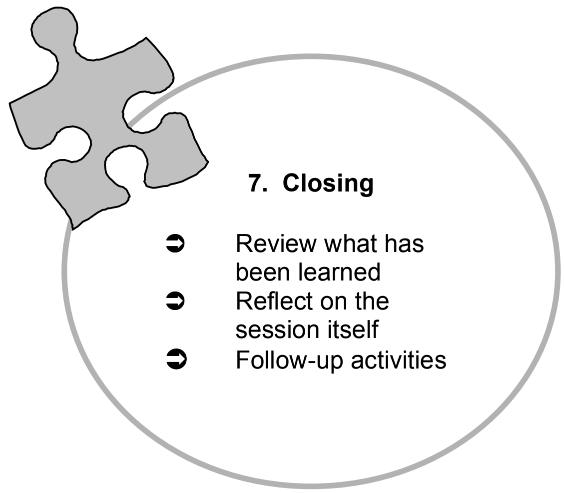
Always:

- ♦ Test for success, never for failure
- ♦ Practice exercises a lot before testing
- ♦ Set easy tests at the beginning
- ♦ Allow trainees to correct their own tests

Possible formats:

- ♦ Individual tests, tests to be done in twos or in teams
- ♦ Multiple choice tests
- ♦ Practical tests on system wiring, maintenance procedures or breakdown services

7.4.7 Closing session



This is the last piece of the puzzle. It is advisable to give ample time to closing activities, to finish the training course well. In any case try to avoid a rush to finish everything.

Activities to review the subjects learned

Closing activities promote recognition that everyone has worked, learned and lived well together. It is necessary to imagine and create pleasant activities to finish on a positive note. Here are some ideas:

At the end of each day	- Fill in the table of participants' expectations expressed as a percentage - Briefly discuss the non-technical aspects of the session (general environment? improvements to be made?) - Straighten up the room together.

At the end of the training course **Celebration!**	- Feedback from the trainees on the entire course (technical and non-technical aspects), in the form of discussions and/or using a questionnaire. - Write the charter of the perfect solar technician. - Discussion of post-training activities of the trainees. - Straightening up the room and equipment together – distribute posters. - Show pictures or video sequences illustrating high points or humorous situations taken during the sessions. - Celebrate work well done: a special meal, gifts, distribution of certificates. - Group photo, exchange of contact information.

Post-training:

After the training course has finished, the trainer(s) should:

- Analyze the results of the trainees' final examinations.
- Analyze the comments from the trainees' feedback about the training course (to learn lessons for future training courses).
- Propose recommendations on actions to be taken after the training (for example further training sessions to be programmed, follow-up of technicians in the field, etc).

7.5 Advice for the optimal use of the training videos

The use of the teaching videos is relatively simple yet very effective[3], especially if one follows the advice below:

☞ Preview the videos several times, before the training session in order to get to know the sequences very well.

When to use the videos?

☞ Watch a video in the following cases :

- As an introduction to a given subject
- To illustrate the practical procedures of an installation
- To relax the atmosphere (change of mode of learning after `too much' theory)

☞ Watch a video before a break, or to have a break: never watch a video after a meal, the effect could be soporific…

☞ Do not hesitate to watch a video several times with a few hours or days intervals in between, without however, boring the trainees.

How to watch a video?

☞ Gather the participants around the television set; (like watching a football game: transform this time together into a moment of pleasure!)

☞ Watch the video with and without the sound. Question the trainees on what they understand or do not understand. As an exercise, ask a trainee to do the commentary following what is seen on the screen.

☞ Split the projection of a video according to specific sequences, rather than playing the whole tape or DVD at once.

If a video camera is available during the training sessions:

☞ Film the practical exercises and if possible, field visits. During the training sessions, replay the most interesting scenes and ask trainees to react by proposing games such as `Find the error', `Questions for a solar Champion'..

[3] Videos of training sessions were used successfully during several training courses for trainers and for technicians in Uganda, Mali, Madagascar, Senegal, Benin and the Democratic Republic of Congo.

7.6 Expectations and feedback questionnaires

Expectations Questionnaire

1. Identification

First name(s) : ____________________

Surname : ____________________

Age : ____________________

Educational level : ____________________

Current job/ area of specialty : ____________________

Employer : ____________________

Complete personal address : ____________________

____

Total number of installations sized / installed / maintained or repaired:	Years of experience in solar installation / maintenance and repair :
Types of installations worked on (small / large scale, private, public):	

3. What are your essential needs? (Tick as many boxed as applies)

	Theoretical	***Practical***
System sizing		
System installation		
System maintenance		
System repair		

3. What are your expectations of this training programme?

____

____

____

____

4. What topics would you like the trainer to give particular attention to ?

____

____

____

____

____

5. What is your state of mind before beginning the training programme?

(Circle 3 adjectives which describe you)

Curious Intrigued Pleased Expectant Sceptical Indifferent

Delighted Easy going Confident Optimistic Untroubled Enthusiastic

Worried Afraid Overburdened Discouraged Irritated Nervous Furious

Training evaluation / Feedback Survey

Trainee name :____________________ (Optional) Date : ____________________

1. *What are your overall impressions of the training programme?*

Mark from 1 (poor) to 10 (excellent)

• The training content was clear	
• The programme was efficient	
• Learning was made easy	
• General atmosphere of the training	

2. *What is your state of mind at the end of the training course (circle three)?*

Pleased – Delighted – Untroubled – Discouraged – Tired – Exhausted – Enthusiastic – Happy – Light – Satisfied – Amused – Sceptical – Confused – Anxious – Sure – Confident – Encouraged – Stimulated – Irritated – Furious – Frustrated - Unsatisfied

3. *What did you appreciate the most, or what was most particularly interesting to you?*

____

____

____

4. *What did you appreciate the least, or what seemed of least interest to you?*

____

____

____

5. *The duration of the course seemed to you :*

• More than sufficient	
• Sufficient	
• Just barely sufficient	
• Insufficient	

6. *Summarize in one sentence your general impression of the training course:*

____

____

____

7. ***Please indicate any specific remarks or feedback you may have on the following;***

- About the pedagogy/ methods used (sequences of the day, training schedules, theoretical lessons alternating with practical exercises, etc)

- About material organization

- About the trainer(s)

- Other remarks

Your suggestions for future training courses

Thank you for your answers.

8 Estimating necessary materials for a training course

8.1 Introduction

Each module begins with a list of the necessary materials for carrying out the sessions related to that module.

The checklist presented here is an overall list of necessary materials for the entire training course. This list will allow you to prepare the necessary materials and the quantities you will need according to the number of trainees. The equipment is categorized as follows:

1. Measuring instruments and tools
2. Specific solar materials (ex: photovoltaic modules, regulators, etc.)
3. Nonspecific solar electric materials (ex: switches, cables, lamps, etc.)
4. Teaching materials (ex: black or white boards, writing materials, projectors, posters, etc.)

The table here indicates the minimum quantities of equipment necessary per session, or per trainee for a training course. Use these minimum quantities in the tables below to calculate the full amount of equipment you will need to procure according to the number of trainees that will attend a given course (based on a minimum of 5 and maximum of 15 trainees per session). Of course, the quantities indicated are not absolute values; they can be adapted on a case-by-case basis.

1/s	→	quantity per session : 1 equipment kit per session of 10 - 15 trainees
1/p	→	quantity per person: 1 equipment kit per person (trainee)
1/2 p	→	quantity per person : 1 equipment kit for 2 people (trainees)
1/3 p	→	quantity per person : 1 equipment kit for 3 people (trainees)

8.2 Measurement instruments / tools

Module	2	3	4	5	6	7	8	9	10	11	12
Electricians tools *	1/2p		1/2p	1/2p	1/2p	1/2p	1/2p	1/2p	1/2p	1/2p	1/2p
Multimeter AC-DC-10 A**	1/2p		1/2p	1/2p	1/2p	1/2p	1/2p	1/2p	1/2p	1/2p	1/2p
Multimeter DC-AC-20 A***	2/s		2/s	2/s	2/s	2/s	2/s	2/s	2/s	2/s	2/s
Clampmeter AC-DC 40 A	1/s		1/s	1/s	1/s	1/s	1/s	1/s	1/s	1/s	1/s
Spirit level				1/3p		1/3p			1/3p	1/3p	
Compass				1/3p					1/3p	1/3p	
Bubble angle finder				1/s					1/s	1/s	
Hydrometer						1/3p			1/3p	1/3p	
Reference PV cell ****			1/s	1/s					1/s	1/s	
Funnel						1/3p			1/3p	1/3p	

Planning Example	
Session with 12 trainees	comments
6	
6	
2	
1	
4	
4	
1	
4	
1	
4	

* Set of electrician's tools including at least: 1 cable stripper, 1 cable cutter, 1 adjustable pliers, 2 flathead screwdrivers, 2 Philips screwdrivers, 1 double tape measure, 1 small hammer

** Multimeter DC / AC 10 A : multimeter with a digital display (budget 10 to 20 €) for DC measurement

*** Multimeter DC / AC 20 A : multimeter with a digital display (budget 50 to 100 €) for precise voltage and current AC measurements

****Or a small module (5 to 10 Wp)

8.3 Solar material and 12 V material

Module	2	3	4	5	6	7	8	9	10	11	12	Planning example: Session with 12 trainees	Planning example: Comments
PV generator													
10 or 20 Wp module mono / polycristaline-12 V			1/s	1/s					1/s	1/s		1	
12 Wp module Amorphous Silicon		1/s	1/s	2/s					1/s	1/s		2	
19 Wp module Amorp Si		1/s	1/s	2/s	2/s				2/s	2/s		2	
40 to 60 module Wp polycrystaline Si -12 V	1/s	1/s	1/s	1/2p	2/s				1/2p	1/2p		6	
40 to 60 Wp module Monocrystaline Si – 12V	1/s	1/s	1/s	1/2p					1/2p	1/2p		6	
Regulator 5 A		1/s			1/s				1/3p	1/3p		4	
Regulator 10 A		1/s			1/s				1/3p	1/3p		4	
Regulator 20 A		1/s			1/s				1/3p	1/3p		4	
2 Batteries 4 Ah 6 V or 1 battery 7 Ah 12 V	1/3p				1/3p	1/3p	1/3p			1/3p		4	
Battery 12 V, 50 to 100 Ah (good condition)	1/s	1/s			2/s	1/s	1/s		1/3p	1/3p		4	
Battery 12 V, 50 to 100 Ah (bad condition)						2/s			2/s	2/s		2	
Loads													
Bulbs : 3 W- 10 W, 12 V	1/2p		1/s		2/s			1/e	1/p	1/p		12	
Bulbs :20 W - 50 W, 12 V	1/2p		1/s		2/s			1/e	1/p	1/p		12	
Fluorescent lamp CFL 8 W / 12 V	1/2p	1/s	1/3p		2/s	1/3p		1/e	1/p	1/p		12	
Fluorescent lamp 13 or 20 W / 12 V	1/2p	1/s	1/3p		2/s	1/3p		1/e	1/p	1/p		12	

Module	2	3	4	5	6	7	8	9	10	11	12
Bulb 100 W - 230 V	1/s		2/s				2/s				
LED light 12 V	1/s	1/s	1/s				1/s	1/s	1/s	1/s	
TV B&W 12 V -15 - 25 W	1/s	1/s	1/s				1/s	1/s	1/s	1/s	
Colour TV 12 and 230 V, 35 to 60 W	1/s	1/s	1/s				1/s	1/s	1/s	1/s	
Tape recorder 12 V and 230 V	1/s	1/s	1/s					1/s	1/s	1/s	
Small radio 3, 6 or 9 V	1/s	1/s	1/s					1/s	1/s	1/s	
Other loads 12 V			1/s					1/s	1/s	1/s	
Fan 12 V					1/s				1/s	1/s	
Damaged fluorescent tube		1/s									
Inverter 100 - 300 W / 12 square signal		1/s					1/s		1/s	1/s	
Inverter 100 - 300 W / 12 pure sinus wave		1/s					1/s		1/s	1/s	
Converter DC – DC		1/s					1/s		2/s	2/s	
Torch (2 batteries)	1/s										

Planning example

Session with 12 trainees	Comments
2	
1	
1	
1	
1	
1	
1	
1	
1	
1	
1	
2	
1	

8.4 standard electric material

This material is generally available in technical training schools. It must be available throughout the entire course duration.

Description	Minimum quantity Per session or per persons	Comments	Planning example: Session with 12 trainees	Planning example: Comments
Rigid or flexible cable 2 x 1.5 mm^2	10 m / 2p	(consumables)	60m	
Rigid or flexible cable 2 x 2.5mm^2	25 m / 2p	(consumables)	150m	
Rigid or flexible cable 2 x 4 mm^2	20 m / s	(consumables)	20m	
Rigid or flexible cable 2 x 6 mm^2	10 m / s	(consumables)	10m	
Fuse holder with fuse 5 A	1 / 3p		4	
Fuse holder with fuse 10 A	1 / 3p		4	
Circuit breakers 10 to 16 A	1 / 2p		6	
Switch (apparent)	5 / 2p		30	
Plug (apparent)	1 / 2p		6	
Connexion box	1 / p		12	
Connector block	5 /2p	(type dominos, various sizes)	30	
Insulating electrical tape	2 / s	(consumables)	2	
Cable ties	200 / s		200	
Screws / nails sets	1 / s	(consumables)	1	

8.5 Teaching materials

			Planning example	
Description	**minimum quantity**	**Comments**	Session with 12 trainees	Comments
Documents				
Trainer manual for teaching solar electricity and small solar systems	1	(1 per facilitator)	1 or ...	(depends on number of trainers)
Practical guide to solar photovoltaic systems for technicians, sizing, installation and maintenance (version 2009)	1/p		12	
Video '*Operation and User Maintenance of Small Solar Systems*'	1/s		1	
Video '*Installation of Small Solar Systems*'	1/s		1	
Other available videos	1/s		1	
Stationery				
Push pins (1 box)	1/s		1	
Scotch tape (large size)	2/s		2	
Color markers (sets of 4 colours)	4/s		4	
Poster paper / flipchart paper (white or colour)	50/s		50	
White chalk (50 pieces box) or whiteboard markers (box of 10)	1/s		1	
Coloured chalk (50 pieces box)	1/s		1	
Colour TV 230 V or 12 V, 40 cm diagonal	1/s		1	
Video recorder, remote control and audio-video cables	1/s		1	
Video projector	1/s	(if possible)	1	
Extension cord with trailing socket	2/s		1	
Notebook or notepad squared 5 x 5	1/p		12	
Pencil	1/p		12	
Drawing pencils	1/p		12	
Calculator (solar by preference)	1/p		12	

MODULE 2 : Units of measure and basic formulae for energy and electricity

1 Objectives

The learning objectives of this module are:

- The principal concepts and laws concerning energy and power.
- The concept of electricity including voltage, current, AC and DC current.
- The concept of electrical resistance (voltage drops in cables).
- The principle units for measuring energy, power, voltage and current.
- Standard representations of electrical components (i.e. drawings).
- Simple electrical circuits.
- Use of multimeters in simple electrical circuits (voltage and current measurements).

2 Module duration

2 – 6 hours

3 Necessary teaching equipment

Description	**Quantity (minimum)**
Torch / Flashlight with batteries	1
Lamp - 8 W – 12 V DC	1
Lamp - 13 W – 12V DC	1
Bulb - 3 W – 12 V DC	1
Bulb - 50 or 60 W - 12 V DC (car headlight)	1
Bulb - 20 to 100 W - 230 V AC	
Dry-cell (1.5 V, size AA)	1
Dry-cell (1.5 V, size C)	1
Small battery 6 Ah - 6 V or 4 Ah - 6 V	2
Battery 12 V with fuse	1
Solar panel 11 Wp	1
Solar panel 20 Wp	1
Solar panel 32 Wp	1
Solar panel 50 Wp	1
Multimeter AC/DC	2
Small cables with crocodile clips	10
Cable 2 x 2.5 mm^2	2 x 25 m
Cable 2 x 0.75 mm^2	2 x 25 m

4 Content

4.1 Different forms of energy

Energy makes things change;energy transforms things

Here are some examples of change that involve energy;

- A woman transporting water,
- A fire cooking foods,
- A bulb or a candle lighting a room.

Each of these changes involves energy consumption. These events are all different, because there are several forms of energy being used to accomplish the change.

4.1.1 Potential energy, heat energy, chemical energy and electrical energy

Potential energy: An object or weight raised to a certain height has energy. A compressed spring has energy. This potential energy is *stored* and waiting to be released.

Heat energy: Calorific energy is energy contained, for example, in a kettle filled with hot water. The hotter the water is, the more energy it contains.

Chemical energy: Chemical energy is stored in fuels, such as gas or wood. The energy stored in a charged car battery or in a new dry–cell is also chemical energy.

Electrical energy : Electricity carries energy from one place to another, for example from a power station to a small town and then to customers.

4.1.2 Solar energy

The sun’s rays reaching the Earth contain energy. They bring changes to the Earth: they provide us with heat, they help plants to grow and dry crops. Without the sun there would be no life on earth.

The sun’s energy is carried in energy *waves*: these waves are either visble ways, infra-red waves or ultra-violet waves. It can also be explained that solar energy is made of energy particles called photons travelling from the sun to our earth. The term **photovoltaic** comes from the word **photon**.

4.2 Energy conversion: the notion of energy efficiency

Energy is constantly being transformed from *one* form to *another.* Whenever this happens, people say that the energy is being ‘used’.

Example of a torch being switched *on*

Chemical energy	> > >	**electrical energy**	> > >	**Light and heat**
(dry-cell)		(electricity in the bulb)		(bulb produces light and heat)

The way in which energy is transformed from one form to another is governed by scientific principles relating to the *quantity and quality* of energy.

4.2.1 Energy laws

Law of quantity

Whenever energy is converted from one form into another, the total quantity of energy remains the same.

In other words, energy is never destroyed, but always transformed or converted. This may seem like excellent news, one may think; the world will always have plenty of energy and will never experience energy crises. However, this is where the second law comes in.

Law of quality

When energy is transformed, the quantity of energy remains the same, but the quality deteriorates or diminishes as it is transformed.

At the end of every energy conversion, heat is produced. Unfortunately, this is low temperature heat energy which is difficult to use again or to use productively.

- A flashlight battery converts chemicals stored in the batteries into electrical energy which lights the bulb. This energy has been transformed into light which is what is needed, but heat is also produced which warms the air around the torch – this energy is not needed and therfore not used productively. The heat energy is produced, but it cannot be used again in any effective way.

Exercise : Light a torch with a incandescent bulb and remove the glass cover. Let students see the light and feel the heat from the bulb. Help them conclude that chemical energy has been converted into light energy and heat energy. Do the same experiment with a white LED torch. It will remain cold as less heat is being produced.

The user does not want this heat produced by the bulb of the torch. But this (useless) *heat* is produced because the energy conversion in the system is not 100 % efficient. Therfore it can be concluded that all systems produce energy that is wasted, often as heat.

4.2.2 Energy efficiency

Because systems often produce energy that can not be used productively, we must then determine how efficient an energy system is. The formula for calculating *energy efficiency* is:

$$\textbf{Efficiency (\%)} = \frac{\textbf{Output}}{\textbf{Input}}$$

Efficiency is always expressed as less than 1, or less than 100%.

Examples of energy efficiency :

- Energy stored in wood or plants / solar energy falling on the leaves = 1 to 4 %,
- Electrical energy from a solar cell / solar energy falling on the cell = 5 to 25 %,
- Electrical energy stored in a battery / Electrical energy needed to recharge it = 75 to 90 %.

> Exercise : On a sunny day, put a 40 or 50 Wp solar panel in the sun, connect it directly to a car incandescent bulb (for example a turn signal bulb of 3 to 5 W, do not use a fluorescent light). Do not connect the light to a regulator or any type of battery.
>
> The bulb will light up (put the bulb inside a room otherwise you might not see the light).
>
> Wait until the module has been outside for at least 15 minutes. Make students touch the solar module. It should be very hot.
>
> Explain to them that while the module is converting solar energy into electricity (the bulb is lit) it also converts solar energy into heat energy (as the module is very hot).

4.2.3 Unit for energy : (Wh)

Energy is measured in *Joule*[1] in the International Unit System. However, this unit is scarcely used in the electricity industry. Electricians use the **Watt-hour (Wh).**

Examples:

- One unit of electricity is: 1 kilowatt-hour (1 kW x 1 hour = 1 kWh).
- One liter of kerosene contains approximately 11 kWh (i.e. 11 000 Wh).
- A 100 Ah C_{100} - 12 V battery contains a maximum of 100 Ah x 12 V = 1200 Wh.

4.3 What is power?

Power is the rate at which work is being done. Whether the work is done slowly or quickly, the same quantity of energy is required.

- Consider two men, each cutting down a similar sized tree. If one man cuts the tree in five minutes and the other in 30 minutes, we can say the faster man has more power. He is a more **powerful** man. However, the energy required to cut the tree was the same for both men as they have done the same job.

- On a sunny day, wet clothes will dry faster than on a cloudy day (i.e. 2 hours instead of the whole day). We can say that the sun has more power when there are no clouds blocking it.

Power is measured in **Watt** or **kWatt (1 kW is 1000 W).**

[1] One joule is the unit of energy corresponding to the work of a force of one Newton moving one meter (1 Joule = 1 W x 1 second ; 1 Wh = 3600 J).

4.4 Relationship between power and energy

Power and Energy are linked by the factor of *time*:

Energy (E) = Power x Time ➔ **E = P x Time** (Wh) = (W) x (h)

> Exercise: If a 40 W TV is turned on for 1 hour, will it consume the same quantity of energy as an 8 W fluorescent lamp lit for 5 hours ?
>
> The answer is : 40 W x 1 hour = 8 W x 5 hour = 40 Wh = Yes!
>
> Ask trainees to calculate examples of energy consumption by multiplying the power ratings of various appliances by a given duration of use.

Remember : Power is the rate at which work is being done. Whether the work is done slowly or quickly, the same quantity of energy is required.

4.5 Basic notions of electricity

> Ask trainees to examine what is written on the following things:
> - on a light bulb (car bulb),
> - on the back of a radio,
> - on the back of a solar module.
>
> They should find the following information: a power rating, an operating voltage, in some cases the operating current and the frequency, etc. Write on the board the information found and comment.

The following information will be found on most electricial appliances; these are the electricial characteristics of the appliance which you can use to calculate its energy consumption:

Information to be found on electrical appliances	Abbreviations	Units
• The power in **Watt** (power consumption for appliances; or power production for generators)	**P**	(W)
• The operating voltage in **Volts**	**U**	(V)
• The current (current drawn by loads; or current produced by generators) in **Amperes**	**I**	(A)
• The type of current	**AC or DC**	-
• The frequency in **Hertz** (only for AC current appliances)	**f**	(Hz)

NOTE: Any appliance or device that consumes electricity can also be referred to as a load.

4.5.1 The two types of current : AC and DC

- Alternating Current (**AC**) : can be produced in several ways; by alternators in power plants, by diesel generators and wind-turbines or by a solar system equipped with an inverter. The current produced by the electricity grid is AC. AC current fluctuates very quickly with time according to its frequency in Hz (i.e. the grid current is equal to zero, 100 times per second). It is so fast that we have the impression that it is constant, however it has a sinusoidal shape.

- Direct Current (**DC**): is produced by: disposable dry-cells (batteries for lamp torches), by solar modules or by batteries such as car batteries. The current and voltage do not fluctuate: they are constant.

4.5.2 Voltage (U)

Voltage is expressed in **Volts**, using the abbreviateion **U.** Voltage is electromotive force or the potential difference of electricity between two points of a circuit. It is the *pressure* that pushes electricity through conductors.

Voltage is always measured by putting the leads of a multimeter on two points of an electric circuit (there is no need to disconnect the circuit).

Exercise: Ask trainees to make simple electrical circuits using batteries or dry-cells, cables and lamps. Measure the voltage across the batteries or dry-cells and the various lamps (using various power ratings). For electrical safety, always insert a protection fuse in the circuit.

Instruct the trainees to draw the various electrical circuits on the blackboard (or in their notebooks) and record their measurements in a table.

Ensure that the trainees follow the correct procedures when measuring voltage:

1. Set the multimeter to the type of voltage to be measured (DC or AC)
2. Set the multimeter to the voltage being measured (12 V, 24 V, 200 V, etc.)
3. Place the multimeter's leads on two points of the circuit (on two terminals of a battery)
4. Record the measurements in a table
5. Double check the measurements for accuracy

4.5.3 Current (I)

Current is expressed in **Amperes**, using the abbreviation **I**. Current is a measure of the 'intensity' of electricity flowing in a circuit. It gives an indication of how much electricity is being used by a particular component, or produced by a solar panel.

Current is always measured by first disconnecting the circuit. The leads of the multimeter are then connected to each of the disconnected ends of the circuit. The multimeter is now in *series*[2] with the components of the circuit and electricity is flowing through the meter. The current can then be measured by the multimeter – set in ammeter mode.

Exercise : Ask trainees to make simple electrical circuits using batteries or dry-cells, cables and lamps. Then insert the multimeter (set in ammeter mode) into the circuit by disconnecting the appropriate wires.
Measure the current being drawn by appliances (same as the ones used in previous exercises) when connected to a small 12V battery.
Ask trainees to draw the electric circuit on the blackboard (or in their notebooks) and record the measurements in a table.

Ensure that the trainees follow the correct procedures when measuring current:

1. Set the multimeter to ammeter mode

[2] It is possible to measure the intensity without disconnecting the circuit, but in this case, it is necessary to have a clamp meter (functioning in DC and AC).

2. Set the ammeter to the type of intensity to be measured (DC or AC)
3. Set the ammeter to the correct current gauge to be measured (the largest)
4. Disconnect the circuit – connect the meter leads to the circuit in series
5. Record the measurements in a table and double check for accuracy

4.5.4 Relationship between Voltage and Current : Power = U x I (DC current)

Exercise:
This relationship can be demonstrated with the voltage and current measurements that were made in the previous exercises:

Use the following table to record the measurements from the previous exercises.

Description of loads	Voltage measured (V)	Current measured (A)	U x I (W)	Power ratings indicated on appliances (W)
Lamp number 1				
Lamp number 2				
Etc.				

Compare the calculated power ratings (U x I) with the power ratings listed on appliances by the manufacturers.

Demonstrate that if the power rating is not listed on an appliance, then it can be calculated by measuring both the current drawn and its voltage.

Demonstrate that if the voltage and power rating of an appliance are known, then it is possible to calculate its current by using the formula : P = U x I.

4.5.5 Relationship between Voltage and Current : Power = U x I x cos φ (AC current)

Cos φ or the Power factor measures the phase difference between current and voltage.

This phase difference depends only on the types of loads.

For example, an AC motor needs active power (U x I x cos φ in Watt for a mechanical power : engine rotation) and reactive power (U x I x sin φ, in VAR for solenoid magnetization). In this case, cos φ is approximately 0.7. If the load is a resistance, there is no phase difference (i.e. lamp: cos φ = 1).

Type of load	Cos φ value	Comments
Incandescent light	1	or an electrical resistance (a resistor)
Fluorescent light AC with electromagnetic ballast	0.5 to 0.8	
Fluorescent light AC with electronic ballast or economic fluo-compact lamp	0.9 to 1	Electronic starter and high frequency power supply (25 to 60 kHz)
Electric motor	0.5 to 0.8 (average 0.7)	the power factor increases with the motor load

To function correctly, a 400 W apparatus with a power factor of 0.8 requires a 500 VA (U x I = P/cos φ = 400/0.8). When the cos φ is low, the currents become more important, involving important voltage drops.

4.5.6 Relationship between Voltage and Current : U = R x I

Voltage (V) = Resistance x Current ➔ **V = R x I** (W) = (Ohm) x (A)

Electrical *resistance* is measured in **Ohm or (Ω)**, and expressed as **R**. This unit measures how well the electricity is being conducted in a circuit.

Resistance can be measured using the multimeter, set as an ohmmeter[3].

Exercise :
Ask trainees to make an electrical circuit using: 12 V car battery, fuse, 20 meters of 2.5 mm^2 cable and one switch to power a 50 W 12V incandescent bulb.
Using the multimeter set as an ohmmeter, measure the resistance of each of the following components; the switch, the length of cable and the lamp.
Switch on the circuit and measure the voltage across the switch, across the cable, across the lamps and across the battery.
Measure the current drawn by the lamp and observe the light output of the lamp.

Be sure to explain the use of the multimeter setting for measuring resistance.
Ask the trainees to draw the electrical circuit on the blackboard (and or in their notebooks).
Have the trainees record their results in a table similar to the one here.

Components	Resistance (measured) (Ohm)	Length of wire (m)	Current (measured) (A)	Voltage (measured) (V)	Calculate R = U / I
Battery					
Wire from battery to switch		1 m			
Switch					
Wire from switch to lamp		19 m			
Lamp					
Wire from Lamp to battery		20 m			

Exercise
Ask trainees:
- to repeat the same experiment using a 0.75 mm² cable (or smaller if available)
- to observe the lamp light output compared to when it was connected to a 2.5 mm² cable
- to draw conclusions about the importance of cable cross section (width), of cable lengths, etc.
- to observe the difficulty of accurately measuring a small value of resistance with an ohmmeter (e.g. cable resistance on a short distance, etc.)

[3] The accuracy of measurement will be low, except for long lengths of cables.

4.5.7 Electric capacity of a battery and stored energy : C = I x t and E = C x U

The capacity of a battery is the quantity of *electricity* it can store[4].

Capacity (C) = Current x Time ➔ **C = I x Time** (Ah) = (A) x (h)

Capacity also indicates the current that a battery can deliver over a given period of time.

If one multiplies this capacity by the voltage of the battery, one obtains the quantity of *energy* stored by the battery. This is expressed in Watt hours.

Energy (Wh) = Capacity x Voltage ➔ **E = C x U** (Wh) = (Ah) x (V)

Energy (Wh) = Current x Time x Voltage ➔ **E = I x Time x U** (Wh) = (A) x (h) x (V)

The battery capacity calculated above is only theoritical. In practice, the energy stored in a battery is always smaller (see **Module 7**)

Exercice :
How much energy is stored in a 75 Ah 12 V battery, when it is 100% charged? How much energy is stored in the same battery, when it is only 50% charged?

Answers :
E = C x U = 75 Ah x 12 V = 900 Wh when the battery is 100 % charged
E = C x U = 75 Ah x 12 V x 50 % = 450 Wh when battery is 50% charged

[4] NOTE: battery capacity depends on many factors, in particular, its mode of discharge (see Module 7).

4.6 Electrical drawings

Now that the trainees have created small electrical circuits, it is time to inform them about national and international codes or standards for drawing electrical circuits.

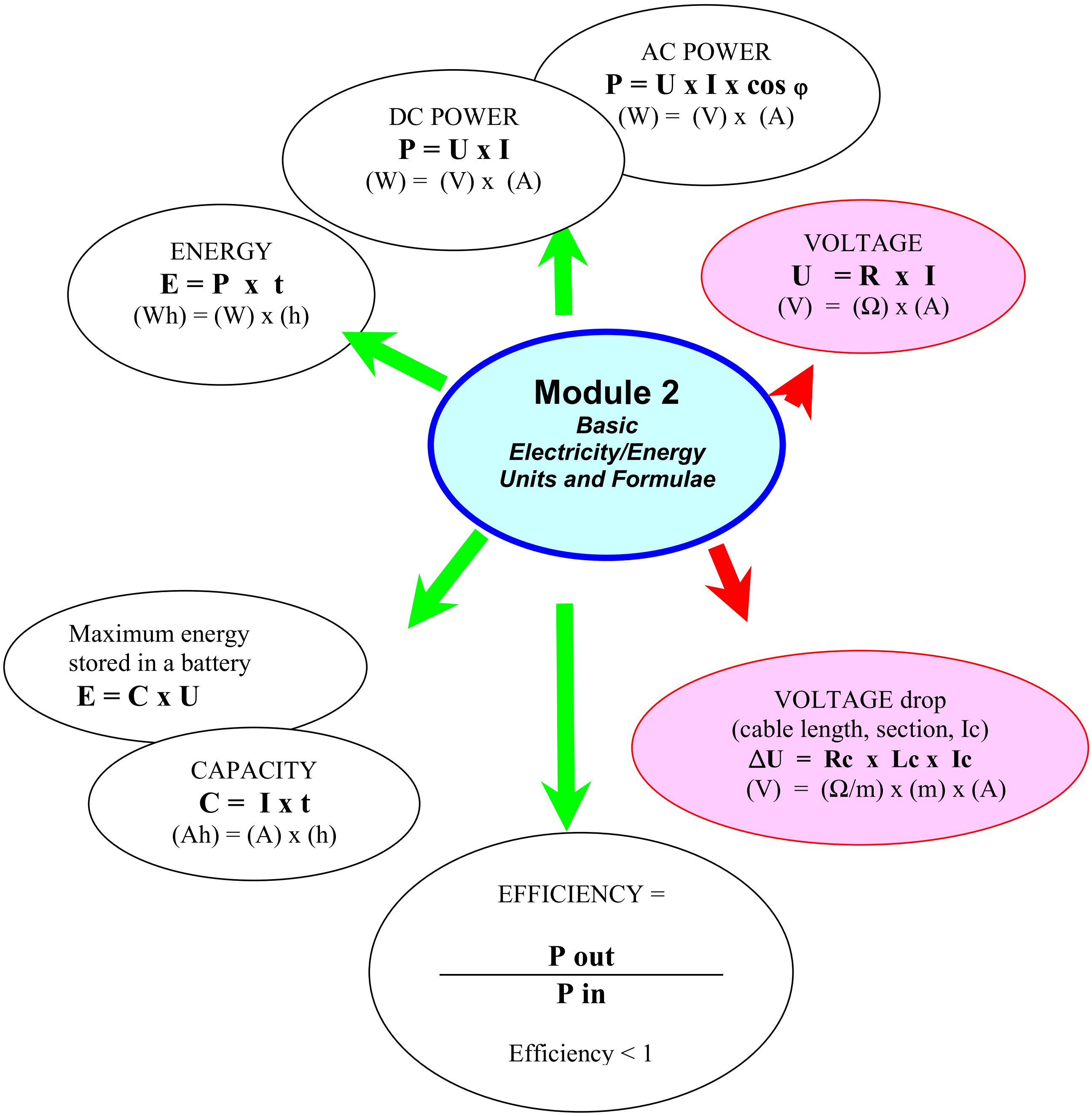
Make a poster explaining the standard drawings or representations of the following equipment:

- solar panel
- battery
- cable (2 wires)
- socket
- connection box
- earthing
- etc.
- regulator
- wire
- switch
- inverter
- fuse
- multimeter (as Ammeter, as Voltmeter, as Ohmeter)

4.6.1 Symbols for French-speaking and English-speaking countries

	Universal symbol	French abbreviation		English abbrevation	
Courant continu	---	CC		*DC*	*Direct current*
Courant alternatif	~	CA		*AC*	*Alternating current*
Intensité (en A)		I		*I*	*Current*
Tension (en V)		U		*V or U*	*Voltage*
Résistance (en Ω)		R		*R*	*Resistance*
Courant de court-circuit		Icc		*Isc*	*Short-circuit current*
Tension en circuit ouvert		Uco		*Voc*	*Open-circuit voltage*
Puissance crête (en watt crête)		Pc (Wc)		*Pp (Wp)*	*Peak power (Watt peak)*

5 Summary diagram



Units used specifically for solar energy:

Wp: denotes maximum power provided by a specific solar module (STC)

W/m^2: unit to measure solar power from the sun (1000 W/m^2 maximum)

kWh/m^2.day: measures the energy received on one square meter of earth /day

6 Evaluation and feed-back

This section is for the Trainers to ensure that Trainees have understood the main concepts presented in this module. The concepts taught here are fundamental for proceeding to the following modules. As such, the trainer needs to assess how well trainees have understood the concepts taught here. This can be done in several ways.

Most importantly, evaluate the strengths and weaknesses of the trainees:

- to choose the right formula, (when making calculations)
- to use a calculator
- to use all the formulae correctly (e.g. P = U x I → U = P / I or I = P / U)
- to remember the units for each concept; energy, power, voltage, current, etc.
- to make sense of the values they measure or calculate by comparing the formulae to values measured with instruments

Any misunderstandings or weaknesses must be addressed and corrected before proceeding.

Finally, trainees can make posters with the most important formulae and electrical drawings, displayed about the room for use throughout the training programme as reference documents.

Important note : if the training course is to result in the qualification of trainees for a certain level, it is suggested to give similar exercises as those that will be given on the examination day.

This has the advantage of preparing the trainees for the final qualification examination and evaluation[5].

[5] Examinations should not be conceived to lead to failure: they should be a true measure of knowledge acquired.

MODULE 3 : Introduction to small solar PV systems

1 Objectives

The learning objectives of this module are:

- Definition of a small solar system.
- Introduction to the main components of a small solar system.
- Teaching the main applications of PV systems and where they are likely to be suitable.
- Teaching the advantages and limitations of PV systems.
- Give awareness about safety and environment issues with new and old equipment.

2 Module duration

3 – 6 hours

3 Necessary teaching equipment

Description	**Qty (minimum)**
Small solar system kit (all components of a small solar system)	1
Solar calculator	1
Electric fan (12 Volt)	1
Broken fluorescent tube or lamp	1
Video 'Installation of Small Solar Systems' or Video 'Operation and User Maintenance of Small Solar Systems	1

4 Content

4.1 Domestic solar systems and other applications of solar energy

Solar home systems (also called domestic solar systems) are one of the most popular solar applications worldwide.

It is important to note as well that solar photovoltaic applications are wide ranging from a few milliwatts for solar calculators to several Megawatts for large power stations.

Since the 1990s, large scale PV applications have become more frequent and popular in Europe, Japan and in the United States. These include facades of office buildings made out of PV modules, large grid-connected power generation stations and housing projects with complete roofs of PV modules (such as the 70 000 house programme in Japan since 1996 or the 100 000 PV roof programme in Germany). Such programmes have significantly increased the production of PV modules world-wide in recent years (from 70 MWp in 1994 to 2500 MW in 2007). This development is leading to a decrease in the price of PV modules. This will in turn benefit small solar system clients in developing countries.

Ask trainees to make a list of PV applications they have heard of and if they have an idea of the power rating of these installations.
Ask trainees to make a poster that will look like the table below when it is filled in.

Type of application	Panel Power range
Solar calculator	Milliwatt
Solar torch / lamp	0.5 Wp
Electric fencing	5-10 Wp
Portable lantern	2 to 10 Wp
Emergency light	2 to 10 Wp
Radio HF, VHF (with or without e-mail connection)	50 to 100 Wp
Small portable phone charger	10 to 50 Wp
Small domestic system for lighting, radios and TVs	10 W to 200Wp
Vaccine refrigerator	100 to 300 Wp
Rural telephone	200 to 500 Wp
Water pumping system	50 W to several kWp
Grid-connected system for homes	1 to 5 kWp
Grid-connected systems on large buildings	5 kWp tp 1 MWp (1000 kWp)
PV power stations	100 kWp to 50 MWp

Ask the trainees what these applications have in common?

The answer is: All the applications above have power ratings that are most often below 1000 W and the loads they are powering are usually smaller than 1000 W.

4.2 Why and when are PV systems an option?

Investment cost is one of the most important restrictions for the spread of PV technology (i.e. module prices from 2.5 to 5 € / Wp in 2008). This has decreased greatly over the years however as it was about 35 € / Wp in 1975.

One of the objectives of this course is to demonstrate that the cost of electricity from PV systems is by far, not the only important issue. Reliability, safety, security and comfort are often cited as reasons why people are willing to pay more to have a PV system.

There are many situations where people are willing to pay more for a solar system than for conventional solutions, such as candles, kerosene lanterns or small diesel generators. Here are a few examples:

Examples

- A small private clinic will want a solar lighting system to replace candles and kerosene lanterns. The clients will go to this clinic because it has good lighting in which the doctor can work in better night-time conditions for patients.
- A bar or a restaurant will attract clients if it can provide music and light all evening thanks to a small solar system.
- A farmer, after the sale of a good coffee harvest, will buy a small solar system to offer good lighting for his children to study in the evening. He or she is making an investment for the family to succeed.

Overall, the cost of solar electricity can be cheaper than extending the grid or buying a diesel generator. Comparisons between systems should be made whenever necessary.

As a rule, PV systems are cost-effective when the quantity of electricity needed (i.e. quantity of electrical energy) is relatively small and where the location has no access to the public grid or where the price of fuel is high.

> Ask trainees to think of activities for which they need energy in their daily life. For which of these activities could they use PV systems?
>
> Let the trainees brainstorm and discuss why in one case PV systems would be suitable and in other cases not.

4.3 Advantages and limitations of solar systems

PV systems, like other technologies, have advantages and limitations. It is very important not to underestimate their limits (e.g. the weaknesses).

People or salespeople, in their enthusiasm, may tend to ignore the limitations and only stress the advantages of solar systems.

To promote a technology, it is a must to be clear and transparent to clients. Future technicians must understand and inform others (e.g. potential clients) about the advantages and the limitations of solar systems.

Activity:

Ask the trainees to make a list of the main advantages and limitations of small solar systems.

Ask them to explain their answers. By analysing their answers, you will have a good idea of what they already know about solar systems.

Make a poster with the answers they have given. Throughout the training programme, this poster can be completed with new advantages and limitations as trainees discover them.

Page 16 of the Paper Tool gives an extensive list of advantages and limitations for reference.

Ask trainees if they have any suggestions to off-set limitations or disadvantages of solar systems.

Activity:

View the video 'Operation and User Maintenance of Solar Systems', section 'Advantages and Limitations of Small Solar Systems' to close this section.

4.4 Safety and environment issues

Small solar systems must be treated as potentially dangerous, just like any other electrical system with a similar voltage, and which contains sulphuric acid (in the batteries).

- Never begin working on a PV system without first understanding its functioning (this is to avoid short-circuits, damaging the equipment and hurting yourself or people around you).

- Before throwing away faulty components, think first whether or not you can recycle them one way or another.

- Read any technical information provided by the manufacturer about recycling or safe disposal.

4.4.1 Battery recycling

- Wherever possible old batteries should be disposed of properly for recycling. The recycled material (especially the lead) will be used to manufacture new batteries. If returning batteries to suppliers or manufacturers is not possible, batteries should be stored in a safe place indoors; far from public access (the electrolyte should be removed and stored in sealed plastic containers).

4.4.2 Fluorescent tube disposal

- Fluorescent tubes contain mercury and rare earth materials which are quite dangerous if spread in water or food.
  If it is not possible to return used or broken fluorescent tubes to suppliers or manufacturers, they should be stored in an indoor place with no public access.

> Show trainees what is inside a fluorescent tube (using a broken tube).
>
> Be extremely careful when handling this sample. It is safe to show this when it is safely inside a tight glass container.

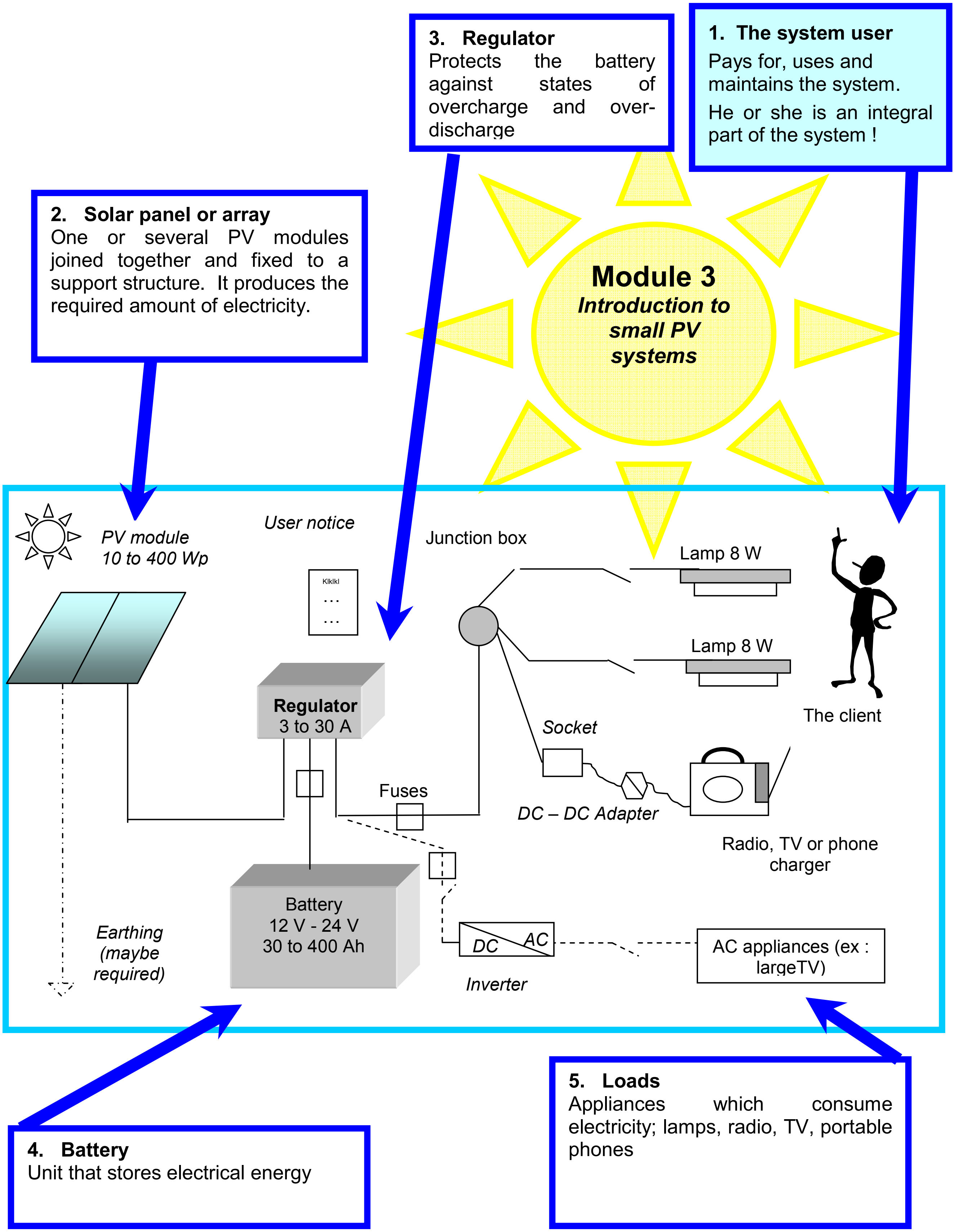
4.4.3 Regulators

- Old regulators which cannot be repaired should be kept in your workshop as you may be able to use some of the electronic components to repair other regulators.

4.4.4 PV module recycling

- Crystalline silicon modules present no hazard to the environment; however some thin film modules (made of Cadmium telluride) should be stored in an indoor place for eventual recycling. PV module recycling is technically feasible but so far it is only done by a few module manufacturers. It is possible to keep a faulty module (with no broken glass) in a workshop for decoration as it can be used to show future clients.

5 Summary diagram



6 Evaluation and feed-back

This section is for the Trainers to ensure that Trainees have understood the main concepts presented in this module. The concepts taught here are fundamental for proceeding to the following modules. As such, the trainer needs to assess how well trainees have understood the concepts taught here.

The following activities can be used to assess what the trainees have learned. Either in teams or individually, ask the trainees:

- to make a poster (or individual drawing in their notebooks) describing a small solar system (electrical diagram)
- to list the advantages and principal limitations of Small Solar Systems
- to describe the safety issues related to Small Solar Systems
- to describe the environment issues related to Small Solar Systems

Important note : if the training course is to result in the qualification of trainees for a certain level, it is suggested to give similar exercises as those that will be given on the examination day.

This has the advantage of preparing the trainees for the final qualification examination and evaluation[1].

[1] Examinations should not be conceived to lead to failure: they should be a true measure of knowledge acquired.

MODULE 4 : The client: meeting his or her needs

1 Objectives

The learning objectives of this module are:

- the importance of understanding the client and his or her energy needs,
- the methods to estimate the client's energy needs,
- the solar resource (solar power, solar energy, and its fluctuations, etc.),
- the relationship between the client's energy needs and the solar resource.

2 Module duration

6 to10 hours

3 Necessary teaching equipment

Description	Qty (minimum)
Halogen lamps; 10, 20 and 50 W	1
Fluorescent lamps; 7, 8, 9 and 11 W	1
A set of various car bulbs (12 V DC)	1
Radio-cassette player	1
Small Radio	1
DC-DC Converter	1
Portable phone charger	1
Multimeters	2
A set of cables and accessories	1
Irradiation data of the country where the training takes place (horizontal plane and on inclined planes)	1
Copy a simplified sizing procedure form (annex 3 of the Guide)	1

4 Content

4.1 Why talk about the client before studying PV technology?

The client or system user, as mentioned in **Module 3**, is an essential *part* of the system; that is why we will talk about him or her, even before studying in detail the technical components of a system. Note: in these documents the term client refers to the system user(s) – although the person who pays for the system may not be the actual user (family members may offer solar systems to parents living in remote rural areas for example).

> Ask the trainees the question 'Why bother talking about the client (the system user) before studying PV technology?'
>
> *The answer is: a successful technician in rural areas should know as much as possible about his or her clients, (at least their energy needs and purchasing power) before trying to sell solar systems.*

Lessons learnt from solar electrification programmes worldwide

These are the most important reasons why we will talk about the user first.

- In the seventies and eighties, a large number of projects introducing PV-technology were implemented in several countries. These projects were basically demonstration and research projects to test and demonstrate new technologies under practical circumstances. Most solar systems were either given to the users or heavily subsidised. These programmes faced the following problems;
  - unreliable technical components,
  - inappropriate designs (wrong sizing),
  - poor installation quality,
  - poor maintenance, lack of spare parts and repair technicians,
  - **poor or no user training on how to use the systems,**
  - short-term commitment of PV system suppliers.

- More recently, technical problems related to components have been overcome. Good quality products are now mass produced, reliable and less expensive (although quality control of equipment purchased is still necessary). However, the critical factors that still need to be considered carefully at the rural level for technicians or promoters of PV systems are:
  - **marketing** : knowing the needs and purchasing power of the client, finding ways to sell appropriately sized solar systems (including financing mechanisms),
  - **client education**, information and training on PV system use to ensure the sustainability of the systems,
  - **availability of qualified PV technicians** trained in technology as well as in marketing / promotion (i.e. willing and able to build long lasting relationships with each client).

From the most recent experiences world-wide, including programmes in Uganda, Mali and South Africa, the critical factor affecting the sustainable market development of solar systems depends **on the relationship between the client and the PV companies or (rural) technicians.**

4.2 The Client is a KEY person

Ask the trainees to make a list of what is essential for a technician to do in order to be successful in rural areas.

Answer : the key elements are listed on Page 19 in the Paper Tool

Draw the equation “Adding up to success” (Page 19 of the Paper Tool)

4.3 Sizing principle of PV systems

This section explains the main factors which need to be considered when sizing a PV system.

It does not cover the detailed sizing process of a solar system. This will be covered later in the course once other technical subjects have been learned (i.e. **Modules 5, 6, 7 and 8).**

Ask the trainees if they have any ideas about the parameters that will affect the size of a solar system.

Draw with them the diagram with the scale on Page 20 of the Paper Tool.

4.3.1 Sizing steps

Sizing of a solar system must be done in 5 consecutive steps.

Ask trainees how they would proceed to size a solar system; which steps would be necessary and then ask them to classify them in the right order.

The answer is found on Page 20 of the Paper Tool.

4.4 Step 1: The client’s energy needs

Ask trainees how they could define the energy requirements of a client (by talking with the client).

The answer is found on Page 21 of the Paper Tool.

A technician should:

1. *Ask what kind of appliances the client wants to use (lights, radios, etc.) and the average period of daily use for each.*
    - Usually, clients find the last part of the question difficult to answer. Clients do not know how long they really use lamps or radios. The technician should help in defining these periods of use as accurately as possible.
    - Moreover, clients do not necessarily know what a solar lamp looks like. It is a good idea to show them the kind of lamps that would be used with a solar system.
    - Set priorities between which appliances will be used and when.

2. *Discuss suitable locations*: It is a good idea to draw a sketch of the house and indicate the proposed position of lamps, sockets for a radio, etc. This will also help to estimate the costs of wiring.

3. *Find out the power consumption of each appliance to be connected to the system.*
   - It is often labelled on the appliances.
   - If it is not known, it is necessary to measure it (see next table).

Table : Typical Power Consumption of Various Appliances

Appliance	Power	Comment
DC current		
LED lamp	1 to 3 W	(LED : light emitting diode)
Lamp with fluorescent tube	4 to 20 W	Power depends on tube length
Incandescent bulbs (in 12V DC)	3 to 50 W	
Halogen bulbs (in 12 V DC)	5 to 50 W	
Radio-cassette player below 6 V	0.5 to 5 W	
Radio-cassette 9 V to 12 V	5 to 20 W	
Black and White TV 12 VDC	12 to 15 W	
Colour TV 10 - 14 inches	25 to 35 W	Special 12V
Colour TV 17 inches	35 to 50 W	Special 12V
DVD Player	10 to 20 W	
Cell phone charger	3 to 20W	
Fan (ceiling)	35 W	
Refrigerator (with compressor)	60W	4 to 10 hours per day
AC current (appliances which will need an inverter)		
LED lamps	1 to 5 W	
Fluorescent lamps	4 to 70 W	Power depends on tube length
Incandescent bulbs	25 to 100 W	
DVD player or VCR	10 to 20 W	
Colour TV 14 inches	50 to 70 W	
Colour TV 26 inches	80 to 200 W	
Digital satellite decoder	15 to 30 W	
Portable computer	30 to 70 W	
Desktop computer	120 to 200 W	
Inkjet printer	20 to 40 W	
Copier	600 to 2000 W	**Never for small PV systems**
Refrigerator	60 to 200 W	4 to 12 hours per day
Electric kettle	1000 W	**Never for small PV systems!**
Iron	1000 to 1500 W	**Never for small PV systems!**
Cooker	1000 to 5000 W	**Never for small PV systems!**

4. *Limit the list of appliances to what can be powered by a cost-effective solar system.* Explain to the customer that irons, electric kettles and cookers consume too much power.
5. *Recommend the most energy efficient appliances, including fluorescent tubes, LED lights rather than light bulbs (i.e. regular incandescent bulbs).*

6. *Last, but not least, use a table to record all these details, like the one below* :

Table : Energy Needs of the Client

Description of load (Make, type, voltage)	Location	Qty	X	Nominal Power* (W)	x	Duration of use (h)	=	Energy consumption (Wh)	Maximum current drawn** (A)
Fluorescent lamp, 12V	Kitchen	1	X	8	X	2	=	**16**	0.67
Fluorescent lamp, 12V	Main room	1	X	8	X	4	=	**32**	0.67
Fluorescent lamp, 12V	Bedroom	1	X	8	X	2	=	**16**	0.67
Radio, 3V	Main room	1	x	5	X	3	=	**15**	0.42
				Total Need		(Nth)		**79**	2.42

* Nominal Power is the power rating (i.e. power consumption) of an appliance. Usually, the power and the voltage are labelled on appliances. If not, calculate the power by connecting the appliance to a power supply (e.g. a battery) and measuring the current and the voltage. Then apply the formula: P = U x I (Formula valid for DC appliances).

If the appliances are AC, use the formula P = U x I x power factor (see also **Module 9**).

** Maximum current drawn can be calculated from the label on the appliance as well (e.g. if the label indicates 8 W – 12V, then use the formula: P = U x I, I = P/U = 8 / 12 = 0.67 A). This formula is valid for DC appliances.

This same table will be used again in **Module 9**. This module deals specifically with the detailed sizing of small PV systems.

Role play:

Two students play a couple (i.e. the clients) owing a house where they want some lights, a radio and a portable phone. All appliances run on 12 V DC.
One student plays a solar technician.

The solar technician has to ask the clients' energy needs and fill in a table (like above) on a blackboard and calculate the energy needs of the couple.

As homework, ask the students to calculate the energy requirements in the house they are living in or they would wish to live in!

Create teams of three or four technicians. Give each of them the following appliances on which you have hidden the power consumption labelling:

- 7, 8, 9 and 11 W-12 V fluorescent lamps,
- 10, 20 and 50 W halogen lamps,
- various 12 V car bulbs,
- a radio-cassette player with a DC-DC converter.
- a 12 V portable phone charger

Ask them to determine the power consumption of each appliance. Let them find out how to proceed on their own, which measuring equipment they need to use, etc.

They will have to make a small electrical circuit to measure the current and operating voltage for each appliance and then calculate the power consumption.

Ask them to compare the power consumption they have calculated with the one labelled on the apparatus.

4.5 The solar resource

4.5.1 Irradiation (kWh / m².day)

Basic principle :

The quantity of electrical energy produced by a photovoltaic module to power appliances is directly proportional to the irradiation where the system will be installed.

It is therefore of the upmost importance to know the values of Irradiation of the area where the system will be installed.

Irradiation is not distributed equally over the surface of the earth for two reasons:

1. Firstly, due to the shape (globe) and declination of the earth, the areas around the equator receive more energy than other parts.
2. The second reason is due to the differences in air humidity, clarity of the atmosphere and clouds and altitudes. There are variations from country to country, even if they are at the same latitude. For example, desert areas, with very dry and clear climates, receive more Irradiation than tropical or equatorial areas where there is more humidity.

These different factors interact to make Irradiation fluctuate greatly from region to region and from month to month.

Read the table on Page 20 of the Paper Tool that shows irradiation in several countries worldwide.

Comment on and discuss geographical and monthly variations (such as dry and rainy seasons).

4.5.2 Maximum power of the sun (Irradiance in W/m²)

On earth, the maximum solar power is approximately 1000 W / m^2 at noon; this happens only when the sun is just above our heads, on very clear days with dry air, no dust, no clouds and no rain. On some rare occasions, it is possible to have peak power of above 1000 W / m².

Ask trainees if they know the total electrical power generation capacity of their country?

Ask them to calculate what would be the size of an area, large enough to capture as much power from the sun.

Let us suppose the answer is 250 MW for a country. (250 MW = 250 000 kW = 250 000 000 W)
To produce this with the solar resource you must calculate; 250 000 000 W / 1000 W/m^2 = 250 000 m^2 which would be a field of 500 m x 500 m or 0,5 km x 0,5 km.
If all the solar energy that falls on this area at noon, and in ideal weather conditions, were converted into electricity then it would be as much power as the country needs!

From this example, it can be seen that the solar power reaching each country is enormous. But is it *always* enormous?

Ask trainees whether the earth always receives the same amount of power from the sun.

As mentioned earlier, the solar power received on earth depends on:

- the weather; rain, white clouds, grey clouds,
- dust particles in the air,
- shading,
- the time of day,
- geographical location (altitude, latitude).

The following exercise is always a success during a training session – do not skip it!

Ask the students to measure the short-circuit current and the open circuit voltage of a solar module every hour and record the results in a table as below:
The module should be placed horizontal (or with a fixed inclination facing the sun)

Date	Time	Description of the weather (sunny, cloudy, rainy)	**Current (A)**	Open Circuit Voltage (V)
	7.00			
	8.00			
	9.00			
	10.00			
	11.00			
	12.00			
	13.00			
	14.00			
	15.00			
	16.00			
	17.00			
	18.00			
	19.00			

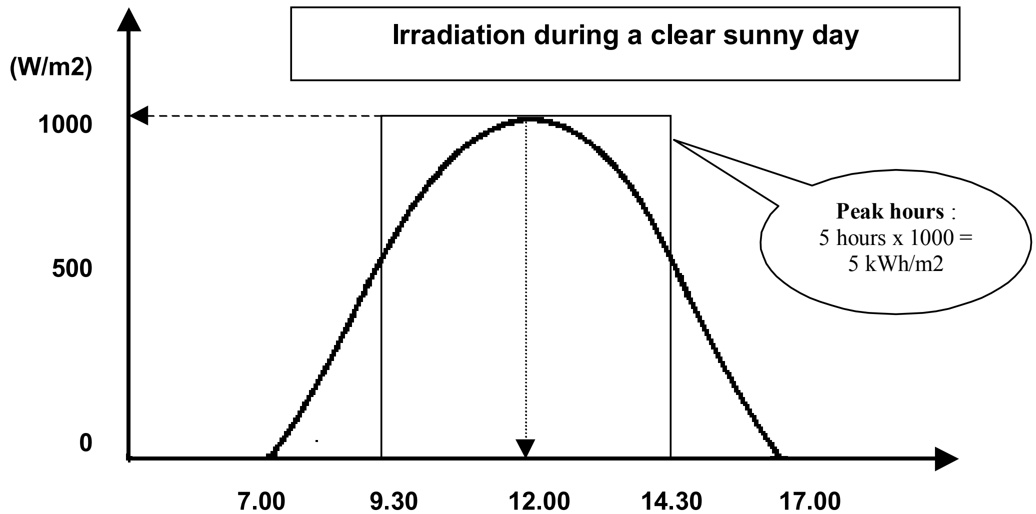
At the end of each day, ask the students to draw a graph of the current and the voltage versus time using the data recorded. Ask them to explain why and how the current and voltage changes during the day.

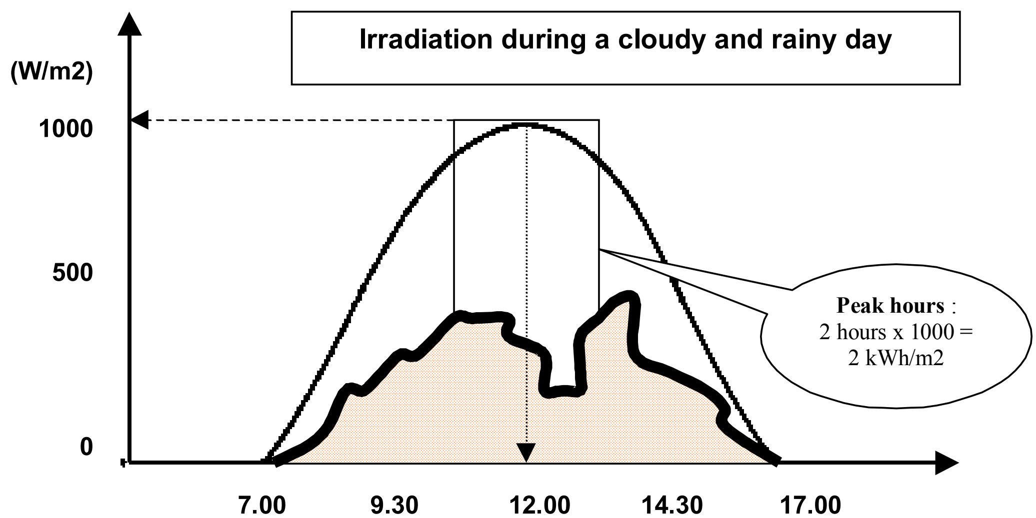
Note: This exercise can be done throughout the entire course. From this practical exercise, trainees can understand that the power of the sun varies greatly during any given day.

4.5.3 <u>How does solar power (irradiance) relate to solar energy (irradiation)?</u>

As we all know, the sun comes up in the morning and goes down in the evening. This means that solar power (irradiance) also goes up and down. Below are typical graphs demonstrating solar power, as it is changes with the time of day.

Draw the graphs below on the blackboard. Ask the trainees if they are similar to the graphs they have been drawing over the past days in the previous exercises.
The graphs should look the same. Conclude that current is proportional to solar power.





As demonstrated above and from the graphs, power varies throughout the day. As the day goes by, the amount of solar energy received on a given surface increases, then decreases.

Irradiation = Solar Power x Time

[kWh / m².day] = [W / m²] x [hours]

Daily weather		Irradiation calculation	
Rainy for 3 hours with a solar power of 300 W/m^2		= 3 x 300	= 0.9 kWh / m^2
Sunny for 3 hours with a solar power of 700 W/m^2		= 3 x 700	= 2.1 kWh / m^2
Cloudy for 3 hours with 500 W/m ^{2}		= 3 x 500	= 1.5 kWh /m^2
		Total	= 4.5 kWh /m^2

4.5.4 Where to find solar resource data

The trainer will need to procure Irradiation data of the main cities and towns in the country where the session is taking place. These data are often available from the Ministry of Energy or internet websites (refer to Page 81 of the Paper Tool).

Show Irradiation maps or irradiation data tables of the country where the training is conducted.

Discuss and point out the geographical and seasonal variations.

An example of irradiation data, showing in the less sunny months (highlighted in grey)

Towns	Kasese	Rukoki Mubuku	Pakwero	Entebbe
January	4.86	5.32	5.44	5.16
February	5.07	5.42	5.30	5.13
March	5.19	5.35	5.28	5.21
April	4.99	5.25	5.09	5.20
May	5.03	5.30	5.34	4.94
June	4.73	5.13	5.09	5.05
July	4.49	**4.67**	**4.38**	**4.66**
August	**4.33**	4.88	4.71	4.92
September	5.06	5.45	5.15	5.23
October	4.86	5.06	5.46	5.19
November	4.98	5.09	5.31	5.19
December	5.22	5.52	5.43	5.12
Average per month	**4.90**	**5.21**	**5.16**	**5.08**

Source: URDT / Meteo dpt. – Data given in kWh / m^2.day on a horizontal surface.

When sizing a solar system, it is advisable to take into account the month which receives the **minimum Irradiation**. This assumes that the user's needs are constant over the year.

This is to ensure that there will be no shortage of power to recharge the battery of the PV system all year round. In fact, by adopting this approach, there will be an excess of energy that the user can benefit from during the sunniest months.

4.6 The Client: meeting his or her needs with the solar resource

By knowing the solar resource and the client's energy needs, one can **estimate** the size of the solar panel using the formula below:

$$\textbf{Module rating (Wp)} = \frac{\textbf{Client's Energy Needs (Wh)}}{\textbf{Irradiation (kWh/day/m}^2\textbf{) x 0.9 x 0.75}}$$

For instance, if the daily Irradiation is 4.5 kWh/m^2 and the energy needs are 79 Wh per day, 79 Wh / (4.5 kWh/m^2 x 0.9 x 0.75) = 26 Wp.

The client's system needs a module with a minimum peak power of 26 Wp.

Important explanations of the above formula:

- This formula takes into account subsequent energy losses in the PV system; Voltage drops in cables, power losses due to the high temperature of the solar module, charge regulator voltage drops and inaccuracy of the solar data are taken into account with a factor of 0.90
- The energy efficiency of the battery is taken into account with a factor of 0.75.
- These values (0.9 and 0.75) are average values of efficiencies that are usually used for well sized systems.
- The module must be clean.
- The module must not be shaded during the day by trees or nearby walls.
- The module must be **well orientated and well inclined** (see **Module 10**).

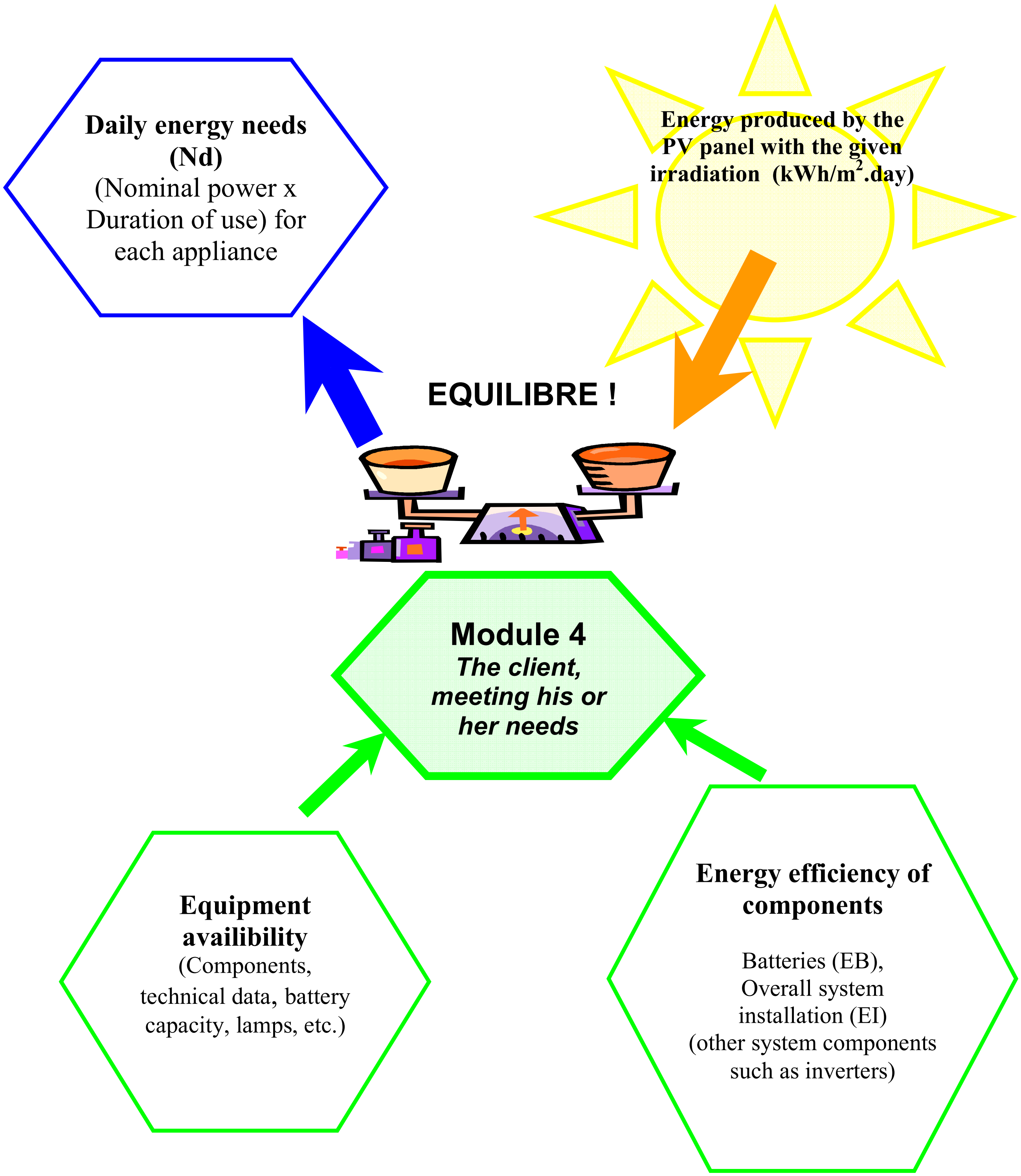
Ask the trainees to calculate the size of solar panel needed to power a 1500 W electrical iron for two hours using the above irradiation data. Draw conclusions with them.

Answer: (1500 W x 2 hours) / (0.7 x 0.85 x 4.5) = 987 Wp

How much would this system cost? This example demonstrates clearly that solar PV systems cannot be used for every electrical appliance.

As mentioned previously, the complete sizing method will be taught in **Module 9**.

5 Summary diagram



Panel peak power = Nd / (Irradiation x EB x EI)

6 Evaluation and feed-back

This section is for the Trainers to ensure that Trainees have understood the main concepts presented in this module. The concepts taught here are fundamental for proceeding to the following modules. As such, the trainer needs to assess how well trainees have understood the concepts taught here. This can be done in several ways.

The following activities can be used to assess learning, either in groups or individually;

- make a poster demonstrating the 5 sizing steps
- make a poster showing the most common appliances used with small solar systems and indicate their power consumptions (summary tables similar to the table : Typical Power Consumption of Various Appliances).
- calculate the energy consumption of a client: 3 lights 8 W each, used for 5 hours per day and 1, 6W radio used 8 hours per day
- explain the variations of Irradiation that occur during the course of a day
- calculate the size of a module needed when the daily Irradiation is 4.5 Kwh/m^2 and for the energy consumption calculated above (3 lights + 1 radio)
- explain why one should use irradiation data from the least sunny month to size a solar system

Important note : if the training course is to result in the qualification of trainees for a certain level, it is suggested to give similar exercises as those that will be given on the examination day.

This has the advantage of preparing the trainees for the final qualification examination and evaluation[1].

[1] Examinations should not be conceived to lead to failure: they should be a true measure of knowledge acquired.

MODULE 5 : Photovoltaic modules

1 Objectives

The learning objectives of this module are;

- the different technologies of solar modules,
- the main technical characteristics of solar modules,
- the energy output from a module and
- quality control when purchasing a PV module.

2 Module duration

8 - 10 hours

3 Necessary teaching equipment

Description	Qty (minimum)
Solar module 10 Wp - mono crystalline	1
Solar module 20 Wp - mono crystalline	4
Solar module 40 Wp - mono crystalline	1
Solar module multi-crystalline (from 20 to 50 Wp)	1
Solar module amorphous silicon 11 or 12 Wp (Naps or Free Energy Europe)	1
Solar module 32 Wp, multi-junction amorphous	1
Any other solar module	1
Solar calculator	5
Multimeters	5
A set of cables and accessories	1

4 Content

4.1 Background and history

The majority of modern PV cells have silicon as their base material, in either mono-crystalline or poly-crystalline formation.

Recently there have been significant developments in the use of thin film technologies which use amorphous silicon, cadmium telluride, copper indium diselenide and other semiconductor substances as the base material.

The solar energy conversion capacity of solar modules increases every year. The PV market is also increasing tremendously each year, while prices are decreasing (see table below).

Year	Maximum PV cell efficiency (in research conditions)	Worldwide production / year	Worldwide bulk price	
1839	-	nil		Photovoltaic effect was first discovered by the French scientist Becquerel
1940	1%	Negligible	-	Photographic meters, light sensors
1960	10%	Negligible	> 100 €/Wp	First solar powered satellite, Vanguard 1 was launched in 1958
1982	13%	5 MWp	20 €/Wp	Remote site systems
2002	25%	1200 MWp	3-4 €/Wp	
2008	30%	3500 MWp	2-3 €/Wp	Most PV systems worldwide are grid connected

Ask the students how much power a module with a 5% efficiency rating would produce if it was 1 square meter large and placed in full sunshine at noon?

The answer is: at noon the irradiation is 1000 W/m2. Hence, the power produced would be 1000 W/m² x 1.0 m² x 5% = 50 W.

Ask the students how much power a module with an 18% efficiency rating would produce if it was 1 square meter and placed in full sunshine at noon?

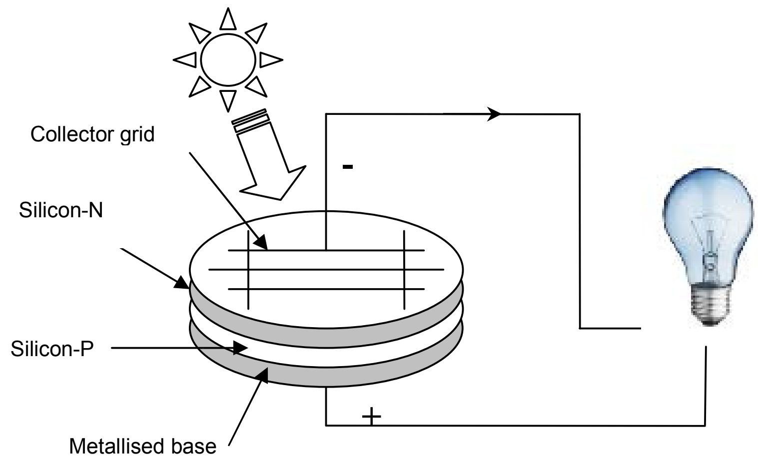
The answer is: at noon the irradiation is 1000 W / m2. Hence the power produced would be 1000 x 1.0 x 0.18 = 180 W.

Ask trainees about the prices of PV modules locally, in the country where the training is taking place.

Compare theses prices with the table above. The local market prices are usually as much as two times more expensive than the international market.

4.2 Diagram – working principle

A silicon solar cell is a large diode sensitive to light. When a photon hits the cell, it excites an electron that will leave its molecular structure, creating a voltage between the two sides of the cells (usually 0.5 to 0.7 V).



4.3 Various types of solar cells

4.3.1 Silicon mono-crystalline cells

A silicon mono-crystalline cell (also called single crystalline silicon cell) is made from a highly pure, thinly-sliced single silicon crystal wafer (0.1 to 0.3 mm thick). The surface of the silicon is treated in various ways which makes it respond to sunlight by developing a voltage between the front illuminated face and the back surface. A network of fine metallic conductors is applied at the front of the cell and the back is metallised all over. An anti-reflective coating is then applied to the front surface. The current produced is Direct Current (DC). The front of the cell is the negative, while the back is positive.

Mono-crystalline cells are generally circular (unless they have been cut to other shapes) and have a uniform blue colour.

A cell of 100 square centimetres (10 cm x 10 cm) will typically produce a maximum of 1.8 Watt with a voltage of 0.5 Volt under full sunshine (i.e. 1000 W / m² or 100mW / cm²).

Show a mono-crystalline silicon module and show its dark blue colour. Point out the network of fine metallic conductors.

4.3.2 Silicon poly-crystalline cells

Silicon poly-crystalline (also called multicrystalline) cell manufacturing costs are generally lower than for mono-crystalline cells, as the cells are cut from a cast ingot made up of multi-crystalline silicon.

The cells are generally square in shape. The cells are blue but display a pattern similar to that of a piece of galvanised metal. The cell efficiencies of poly-crystalline are slightly lower than for mono-crystalline.

> Show a poly-crystalline silicon module and point out the pattern on each cell.

4.3.3 Single amorphous silicon cells and modules

Amorphous silicon cells are made using a thin film of amorphous silicon (also referred to as amorphous-Si). Less material is used in the manufacturing process, thus lowering their cost.

Their main disadvantage is that their performance decreases during the first months post-production with their efficiency eventually stabilising at 4-6% for commercially-available modules.

Because their efficiency is low, the size of a cell with a given power rating needs to be at least twice as large as a corresponding silicon crystalline cell.

The cells are dark brown and arranged in layers, separated by thin lines.

Amorphous silicon modules can easily be manufactured at the required voltage and power by literally cutting the module to size. Amorphous silicon modules are most commonly manufactured in sizes ranging from less than a watt (e.g. for a solar calculator) up to a maximum of 50 watts.

> Ask the trainees to look at their solar calculators. Ask them what kind of solar modules they are? Are they mono-crystalline, poly-crystalline or amorphous silicon cells?
>
> Show an amorphous module and ask them to count the number of thin lines and calculate the open voltage.
>
> They should find about 36 cells. All cells are in series, so that the open voltage is 36 x 0.5 V = 18 V.
>
> Then ask the trainees to measure the open voltage with a multimeter, set as a voltmeter. Conclude with them that by counting the number of cells, you can estimate the open voltage (Uoc). This is valid for most types of solar modules.

> Exercise: Show an amorphous-Si module and a crystalline silicon module (ideally both modules should have the same Peak Power).
>
> Ask the trainees to compare their power output (by reading the labelling) with their physical size (by measuring the surface area of the modules).
>
> *Answer: If they are of similar peak power, the amorphous silicon one is about twice bigger because the efficiency of the amorphous module is lower than the crystalline module.*

4.3.4 Multi-junction amorphous silicon cells and modules

These cells are also made of amorphous silicon material but they are made of multi-junction layers, with each additional layer being receptive to an additional part of the light spectrum. They achieve greater efficiencies than basic amorphous silicon. Progress in manufacturing these types of modules (i.e. UNISOLAR modules, triple junctions) has led to a good cost performance ratio.

These modules are quite light and almost unbreakable as they are not made of glass. They use an innovative plastic material to protect the cells instead of glass.

When first deployed, these types of modules generate 10 to 15% more power output than their ratings. This is to take into account a power attenuation which will occur in the first several months of deployment.

4.4 Photovoltaic modules

In a photovoltaic module, photovoltaic cells are most often connected in series.

They may however be connected in parallel some of the time, or a combination of both, to produce the required power at an appropriate voltage.

All PV cells are encapsulated in a clear weather-resistant laminate, and usually enclosed in a sturdy, corrosion resistant frame to form the module. This is to give the modules a long lifetime.

Most module covers are made of glass: modules should be handled gently.

4.4.1 Monocrystalline and polycrystalline silicon modules

A photovoltaic module, either silicon mono or poly-crystalline, typically comprises 36 cells connected in series to achieve a voltage of 16 V to 20 V, suitable to charge a 12 V battery.

A typical module is 0.4 m x 1.0 m in size and will produce a maximum of about 50 to 70 Watts of direct current (DC) at about 15 Volts.

Since in some applications, such as small portable lamps, a typical module is much larger (and more expensive) than necessary, smaller modules are manufactured which use half-cells or quarter-cells to achieve the same voltage as the full size module, but with a quarter or half the power.

Ask the trainees to measure the size of the cells in the following modules (for example):
- A 10 Wp module,
- A 20 Wp module,
- and a 40 Wp module.

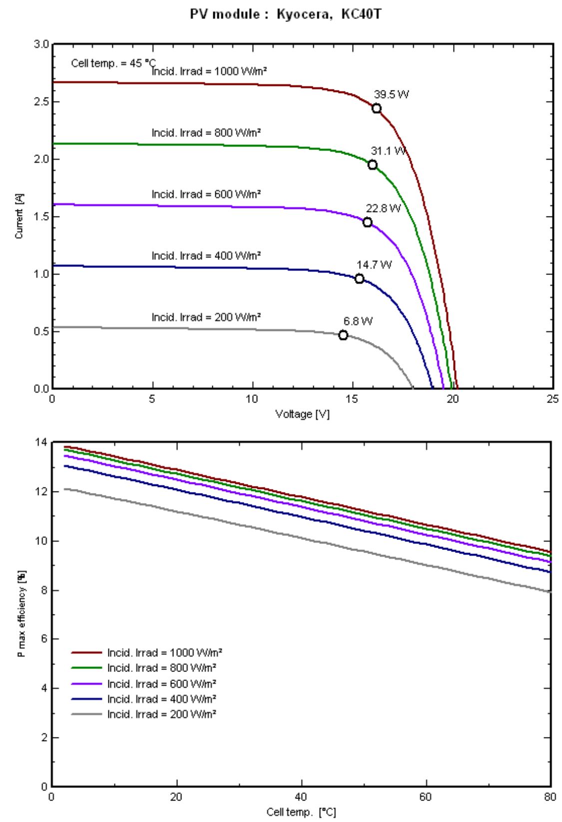
Ask them to read the power ratings written at the back of the module. Help them to see that the cell size of the 10 Wp module is twice smaller than the 20 Wp module, hence the power is two times less. Demonstrate the same reasoning with the 40 Wp module compared with the 10 Wp.

Conclude: The power of a given type of module depends only on the size of the cells.

4.5 Main characteristics of a PV module

4.5.1 Module peak power or module power rating: Pp or Pmax

Refer to the definitions for these terms on Page 13 and Page 25 of the Paper Tool; refer also the IV curve (Page 27 of the Paper Tool).



- Power output is almost directly proportional to the short-circuit current, hence to the irradiation received on a module and to the size of each cell
  (You can draw this curve using a 40 Wp module with 36 cells).

- On average, power output decreases by 0.5% per °C when the module/cell temperature is greater than 25°C.

  Therefore it is always important to let air flow around the modules to allow for cooling and to limit power losses. For this reason, modules should never be installed directly onto corrugated sheet roofs; modules should be installed at least 20 centimetres above the roof surface.

- Modules produce heat when they are facing the sun. This is normal, as they only convert between 5 and 20 % of the sun's energy into electricity; the rest of the solar energy is dissipated as heat.

4.5.2 Open circuit voltage: Uoc

Uoc is measured with a multimeter (set as a voltmeter) when the module is not producing any current.

- The open circuit voltage is directly proportional to the number of cells in series in a module. As Uoc is about 0.5 to 0.7 V for each cell, a module with 36 cells in series has an open circuit voltage of 36 x 0.6 = 21.6 V).

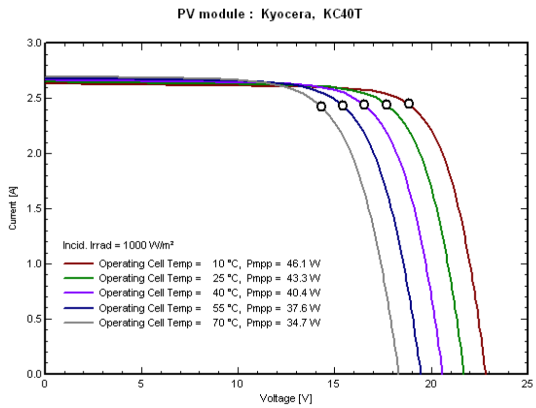
> Ask the trainees to measure the open voltage of the following modules (for example):
>
> A 10 Wp module,
> A 20 Wp module,
> and a 40 Wp module.
>
> Conclude that the open voltages are the same because the number of cells in series in each module is the same (i.e. 36 cells).
>
> *The open circuit voltage depends only on the number of cells, not their size!*

- The open circuit voltage is almost constant whatever the irradiation level.

Ask the trainees to measure Uoc with at least 2 different modules and record their measurements every hour from 8h00 to 17h00 (this exercise may have been done during Module 4).

At the end of the day, help them conclude that Uoc remains more or less constant between 16 V and 21 V even if the weather is cloudy.

- The voltage decreases with temperature (70 mV to 114 mV/°C)



Ask the trainees to measure Uoc with a cold module (a module inside) and then a warm module (a module left out in the sun) with the same irradiation (at the same moment).

Help them conclude that Uoc decreases when the module becomes hot.

4.5.3 Short-circuit current : Isc

The short-circuit current is the current produced by a module when it is short-circuited by a multimeter set as an ammeter.

IMPORTANT : It is safe to short-circuit an unconnected solar module as the current is limited by the power of the sun (refer to the IV curve on page 27 of the Paper Tool)

However, one should never short-circuit a module when it is connected to a regulator or to a battery.

- Isc is directly proportional to the cell size. For example a module with cells of 10 cm x 10 cm square will have an Isc two times greater than a module with cells of 10 cm x 5 cm.

Ask the trainees to measure the short-circuit current of the following three modules; the 10, 20 and 40 Wp modules. Measurements have to be made at the same time to compare the modules.

Help the students to conclude that the Isc is directly related to the size of the cells of each module.

- The short-circuit current is directly proportional to the amount of sunshine.

Ask the students to measure Isc from 8h00 to 17h00 every hour for at least 2 different modules.

All results should be convincing enough to make them conclude that the Isc increases or decreases directly with the amount of sunshine. You can also take a module and measure its Isc at several orientations and inclinations, and show how Isc also varies as quickly as you move the module (while Uoc does not vary that much).

4.5.4 The junction box and diodes

Current is transferred from the module via a junction box which is attached to the back of the module.

Inside the junction box of large modules (greater than 40 Wp), diodes are present. They are called by-pass diodes. They are most useful for large PV systems. For small systems, they can simply be removed if they are blown out (burnt) by lightning.

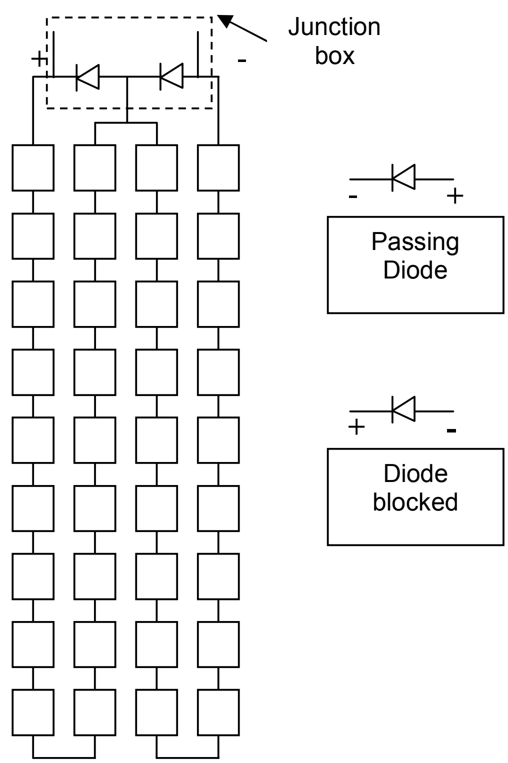
Bypass diodes

These diodes are placed in parallel for each of the 18 cells in series. Most modules have 36 cells; hence they are equipped with 2 by-pass diodes.

When all the cells produce electricity, the diodes are blocked. However, when one or several cells are shaded, the diode of this string of 18 cells becomes electricity conductor.

Diodes are necessary for systems greater than 24 V (i.e. when two or more modules are connected in series). In this case, they will bypass the current that would otherwise cross the shaded cells which can create a "hot spot" that can damage the cells.

If bypass diodes have been installed by the manufacturer, they should be left in place, even if the system is 12 V.



By-pass diodes in a 36 cell module

Blocking diodes

Blocking diodes are used to prevent current from crossing modules in the reverse direction: either current from the battery or from other arrays of modules. They are not necessary in the following cases:

- If the regulator is already equipped with a blocking diode (most have one).
- If the energy loss caused by the diode ($E = U_{diode} \times I \times t$) during the day is greater than the energy lost during the night.

4.5.5 Table: Analysis of module price versus warranty for major module types

	Module efficiency	Price per watt (USD/Wp)*	Warranty from manufacturer (years)**	Years experience with the technology
Silicon monocrystalline	14 to 18%	3 – 5	10 to 30	40
Silicon poly-crystalline	12 to 14%	3 – 5	10 to 25	25
Silicon amorphous	4 to 7%	3	5 to 20	20
Silicon multi-junction and other thin films	8 to 10%	3	5 to 20	10

**Prices indicated are those on the world market, not local retail prices.*
***Warranties : PV module manufacturers guarantee that modules will produce at least 80% of their nominal power output after 5, 10, 20 or even 25 years.*

4.6 Association of modules in parallel and in series

Solar panels can be connected in parallel or in series. The demonstration of this concept is best done through practical exercises.

> Ask the trainees to connect 2 or 3 solar modules of equal Pp in parallel and measure Uoc and Isc.
>
> Then connect one 20 Wp module in parallel with a 40 or 60 Wp module and measure Uoc and Isc.

Rules: modules in // (parallel)

The current produced by the array is the sum of the current produced by each module.
$\mathbf{Isc_{Panel} = Isc_{module\ 1} + Isc_{module\ 2} + Isc_{module\ 3}}$

The panel voltage is equal to the voltage of each module.
$\mathbf{Uoc_{panel} = Uoc_{module\ 1} = Uoc_{module\ 2} = Uoc_{module\ 3}}$

The panel power output is equal to the sum of each module power output.
$\mathbf{Power_{Panel} = P_{module\ 1} + P_{module\ 2} + P_{module\ 3}}$

To increase the solar panel power of a system, one needs to add extra modules with the same open voltage, even if they have a different Pp.

> Ask the trainees to connect 2, then 3 solar modules of equal Pp in series and measure Uoc and Isc.

Rules: modules in series (same power output)

The panel current is equal the current of one module.
$\mathbf{Isc_{panel} = Isc_{module\ 1} = Isc_{module\ 2}}$

The panel voltage is the sum of the voltage of each module.
$\mathbf{Uoc_{Panel} = Uoc_{module\ 1} + Uoc_{module\ 2}}$

The panel power output is equal to the sum of each module power output.
$\mathbf{Power_{Panel} = P_{module\ 1} + P_{module\ 2}}$

Note: there is no need to connect modules in series unless your system has a 24 V battery to recharge

> Ask the trainees to connect a 20 Wp module in series with a 40 Wp module and measure Uoc and Isc.
>
> *Conclusion: The resulting current is that of the smallest module and the voltage is the sum of two voltages. NEVER connect modules of different power ratings in series, as the smallest module will always impose its current. In some cases, the smallest module may be damaged as well.*

4.7 Energy from solar photovoltaic modules

The approximate energy produced by a module over a day can be calculated with the following formula:

Maximum module output (Wh)	**=**	**IRR (kWh/m^2.jour) x Pp (Wp)**

where **Pp** = Peak power of the module
IRR = Irradiation in the plane of the module, determined from meteorological data

IMPORTANT: This formula is valid only if the module is able to receive the given irradiation. For this to happen, it is necessary that:

- the module is **well orientated and well inclined to receive the irradiation!**
- the module is clean and
- the module is not shaded by any trees or nearby walls.

Ask the trainees to calculate several maximum module outputs using local or national irradiation data.

4.8 Quality control when purchasing modules

Most solar modules are produced with high quality standards by module manufacturers. However, solar module retailers do not always market the modules for what they are.

One needs to know that two modules of the same technology / brand name and physical size may have a 10 to 20% difference in Peak Power between them. This is not a problem as such provided these modules are clearly identified as producing different power outputs.

Important advice:

- Before purchasing a module, always look at the back of the module for the following information:

Peak power (Wp) under standard conditions	**53 Wp**	Under standard test conditions : 1000 W/m2, temp. 25°C
Open circuit voltage (V) **Short-circuit current (A)** Power maximum at load Voltage at load Current at load	**21.8 V** **3.27 A** 53 W 17.4 V 3.05 A	Idem Idem

Example of module labelling – some labels will give you more, or less information. Some labels will also give the module power output under real conditions (e.g. 800W/m2, 60°C) while some labels will indicate only the brand name.

- *Give preference to buying a solar module with a detailed label on the back. If possible, discard a module without any labelling.*

- *Give a preference to modules that are conform to the norm IEC-61215(for crystalline modules) orIEC-61646 (for amorphous silicon modules).*
- *If the label is not available, ask the solar module vendor for more information about the module (a technical data sheet).*
- *Give preference to modules with a serial number engraved in the laminate.*

Show a module with an engraved serial number.

- *Do not buy a solar module based on its physical size! Two modules of the same technology, brand name and physical size can have power ratings of 42 Wp and 52 Wp respectively! Read the labelling!*

Using technical documents from various modules, show trainees the differences in Peak Power with modules of the same brand name and physical size.

- *If there is no adequate labelling at the back of the module and, as a last resort, it is a good idea to measure the short-circuit current of the modules when purchasing them. You can then compare this Isc with a module that you know very well.*
- **Calculate the price per Watt peak – in local currency and in €uro / Watt peak.**

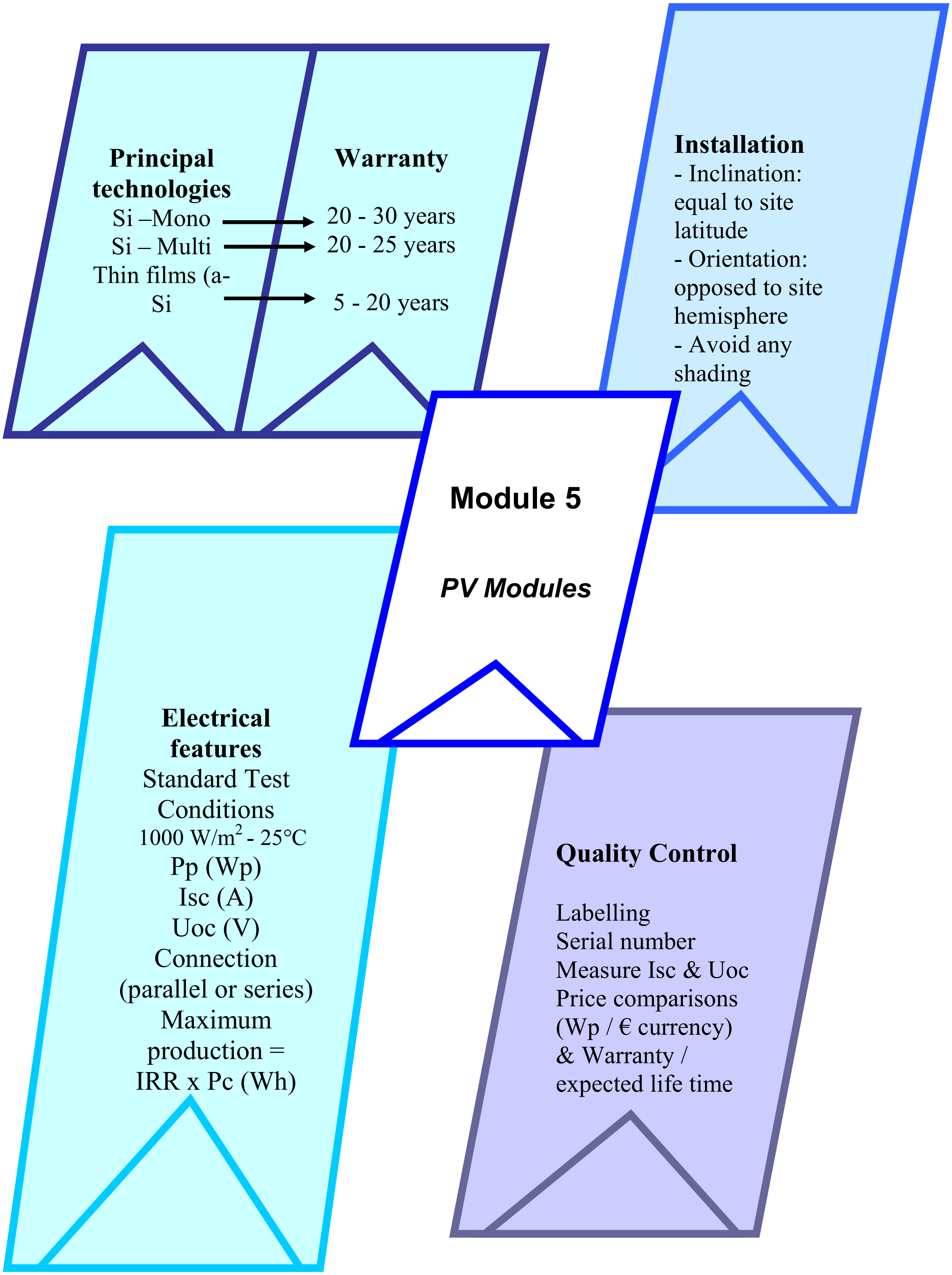
It is very important when buying a module to divide its price by its maximum output. That is of course, if there is enough reliable information about the validity of the Peak Power of the module (i.e. adequate labelling).

A client needs a panel of 20 to 22 Wp. Tell the trainees that they have a choice of buying a 20 Wp module (crystalline silicon) that costs 330 € or two modules of 12 Wp (armorphous silicon) that cost 140 € each. Ask them which one is the best option? *The 20 Wp module costs: 330 € / 20 Wp = 16.5 € / Wp* *The two 12 Wp modules cost: 280 € / 24 Wp = 11.6 € / Wp* *In terms of price per Wp, the amorphous silicon modules are less expensive. The choice however is not that easy as the buyer needs to be certain that the 12Wp will last as long as the crystalline module.*

- **Compare the price per Wp with the expected lifetime of the module i.e the number of years guaranteed by the warranty.**

Is it wise to buy 2 modules costing 11.6 € / Wp with a 5 year warranty (an expected life between 5 and 10 years) instead of a module costing 16.5 € / Wp with a 20 year warranty (and an expected lifetime 30 years)? Discuss these issues with the trainees. *Conclude that the choices should be left to the client, but he or she should be informed by the PV technician, which is not always the case in real life. Indeed, quite often, one tries to sell slightly cheaper modules without informing clients that the warranty is much shorter.*

5 Summary diagram



6 Evaluation and feed-back

This section is for the Trainers to ensure that Trainees have understood the main concepts presented in this module. The concepts taught here are fundamental for proceeding to the following modules. As such, the trainer needs to assess how well trainees have understood the concepts taught here. This can be done in several ways.

Suggested activities to be carried out in teams, individually or as an individual session:

- Briefly describe the 3 main types of solar modules.
- Detail the three main electrical characteristics of a solar module (answer is Pp, Isc and Uoc).
- Explain how to connect 3 modules of 50 Wp (Ioc = 18V) to make a 200 Wp (Ioc = 18 V) panel.
- Explain why it is possible to connect a 30 Wp in parallel with 80 Wp module to make a 120 Wp panel.
- Calculate the amount of energy produced by a 40 Wp module during one day in a site where the Irradiation is 2 kWh/m^2, then 4.5 kWh/m^2, and finally 6 kWh/m^2
- Calculate the amount of energy produced by a 12 Wp module during one day in a site where the Irradiation is 2 kWh/m^2, then 4.5 kWh/m^2, and finally 6 kWh/m^2
- Make a list of things or parameters to consider when purchasing a solar module.

Important note : if the training course is to result in the qualification of trainees for a certain level, it is suggested to give similar exercises as those that will be given on the examination day.

This has the advantage of preparing the trainees for the final qualification examination and evaluation[1].

[1] Examinations should not be conceived to lead to failure: they should be a true measure of knowledge acquired.

MODULE 6 : Charge regulator

1. Objectives

The learning objectives of this module are:

- the role of the regulator,
- the main technical characteristics of the regulator,
- selection of a regulator and
- quality control when purchasing a regulator.

2 Module duration

4 – 6 hours

3 Necessary teaching equipment

Description	**Qty (minimum)**
Regulator 10 A	1
Regulator 15 A	1
Module 20 Wp, BP Solar	1
Lamp 8 W fluorescent	1
Battery sealed 7 Ah / 12 V	1
Multimeters	4

4 Content

4.1 The Functions of a regulator

A regulator's main purpose is to prevent damage to the battery from over-charging or over-discharging. It is the brain of the domestic solar system; so, like the brain of a human being, it is a delicate and fragile component.

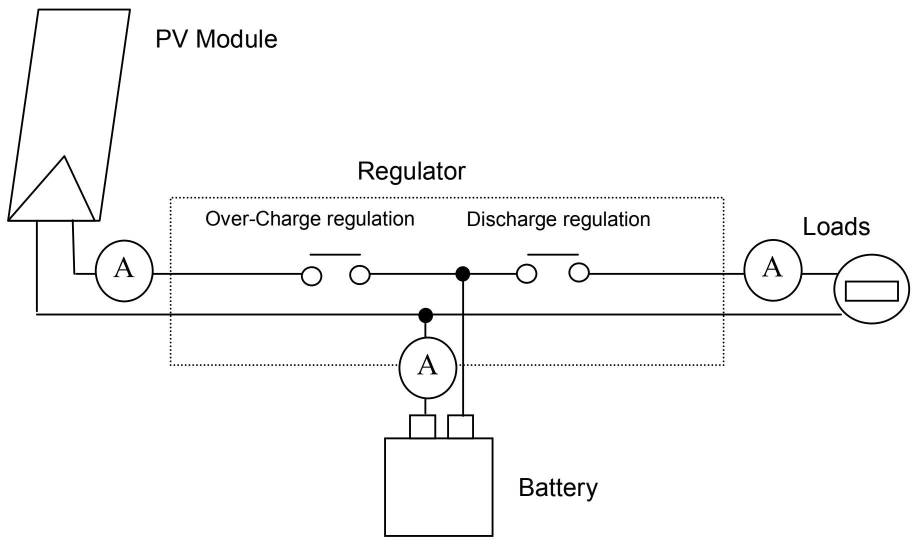
As can be seen from the system diagram (in **Module 3**), the control unit is a centrally located device in the PV system. The regulator performs the following functions:

1. The regulator directs electricity generated by the PV module(s) towards the end use (the loads) if the time of electricity demand coincides with sunshine hours (e.g. when listening to the radio during the day).
2. The regulator directs electricity generated by the PV module(s) towards the battery in cases of excess of solar power (e.g. power generated greater than the power consumed by the radio).
3. The regulator directs electricity generated by the PV module(s) to recharge the battery as quite often the electricity from the battery is used at night.
4. The regulator directs the electricity from the battery to the point of end-use when the demand exceeds the power generated by the PV module.
5. The regulator prevents the battery from being over-discharged, by cutting-off the loads if the battery is too discharged.
6. The regulator prevents the battery from being over-charged, by cutting-off the charge from the panel when the battery is fully charged.
7. The regulator prevents damage from short-circuits in cables (when they are equipped with internal fuses).
8. The regulator gives indications about the functioning of the PV system and the state of charge of the battery.

> Ask trainees to draw a schematic diagram of a solar system (similar to the one given in Module 3). Make them explain each point above and show the current flows for each of the points above.

> On a large table, ask the students to lay out and wire a small solar system with the following components:
> - 1 solar module (20 to 40 Wp)
> - 1 charge regulator
> - 1 battery 7Ah / 12V (or 2 x battery 4h / 6 V in series)
> - 1 lamp of 8 W
> - 1 fuse between the battery and the regulator and a fuse between the lamp and the regulator
>
> Insert 3 multimeters (set as ammeters) to measure :
> - current between the regulator and the module
> - current between the regulator and the battery
> - current between the regulator and the lamp
>
> Insert a voltmeter to measure the battery voltage.

With the trainees, experiment with the system to demonstrate the 8 roles of the regulator listed above. Be careful not to create a short circuit when demonstrating number 7.



4.2 Main characteristics of a regulator

These are listed on Page 28 of the Paper Tool. Some are explained in detail here.

4.2.1 Maximum admissible current

Regulators should be chosen according to the currents that will pass through them. The current from the panel should be capable of going through the regulator without over-heating the unit. A regulator should also be able to withstand the current from the battery to the loads, without any over-heating (this is called the maximum current deliverable to the loads).

In most cases, the charge regulator is crossed by the following maximum currents:

1. The **maximum short-circuit current (Isc)** of the PV panel[1]
2. The **maximum current deliverable to the loads** when they are all switched on.

Let the trainees determine the Maximum current values of regulators by reading the technical documentation supplied with the regulators you are using for this training.

4.2.2 Regulator indicators

Regulators often have LEDs (light emitting diodes), voltmeters or LDC displays which serve as indicators for:

- whether the module is charging the battery,

[1] The charging current will often be lower than Isc, however it may happen that due to albedo (sun ray reflexions from clouds) than the charging current exceeds the Isc of the panel.

- whether the battery is full, half full or empty,
- whether the loads have been disconnected because the battery was too discharged, and
- whether there is any electrical problem detected by the regulator (short-circuit, reverse polarity, etc.).

> Display several types of regulators and let trainees guess which indicators mean what.

4.2.3 Regulator voltage thresholds

The following exercise is very important to do. Do not skip it.

> On the blackboard reproduce the diagram from page 73 of the Paper Tool without noting the voltage values.
>
> Using the PV system wired at the beginning of this module, perform the following exercise:
>
> - Switch OFF the lamp and wait until the module has fully charged the battery. Have trainees measure the voltage of the battery. The voltage should stabilise at around 14.1 V (this will depend on the type of regulator chosen). This is the threshold voltage to protect the battery from over charging.
>
> - Place a dark cover on the module (to simulate night time) and switch the lamp ON. Measure the voltage as it drops. Keep measuring until the lamp is AUTOMATICALLY switched OFF by the regulator. Measure the voltage at which the lamp switched off. It should be around 11.3 V (this will depend on the type of regulator).
>
> - Remove the dark cover from the module (to simulate daylight) and measure the voltage increasing. Measure the voltage when the lamp is AUTOMATICALLY switched ON by the regulator. Record the voltage at which the lamp switches ON. It should be around 12.7 V (this will depend on the type of regulator).
>
> - Have the trainees compare if these values correspond to the values given in the technical documents of the regulator unit.
>
> - Repeat these experiments using other regulators, and compare results.

> As a further demonstration of regulator function, draw with the trainees the charging voltage curve of one or two regulators. This is a graph with Time as the horizontal Axis and Battery voltage as the vertical Axis).
>
> This allows trainees to visualise the regulator behaviour over time.

Most regulators have pre-set voltage thresholds. On some regulators, you can modify them using 'modifying bridges' to suit the type of batteries you are using ("open" or "sealed" batteries).

4.2.4 Temperature compensation for the end-of-charge voltage threshold

The end-of-charge voltage of a battery is determined for a given temperature, usually 25°C.

If the temperature of the battery is greater than 25°C, which is often the case in the countries with strong fluctuations of temperature during the day or according to seasons, the regulator must necessarily (to avoid a strong distilled water consumption and to damage the battery) reduce the end-of-charge voltage, by applying the following factor: - 18 to -30 mV/°C (value valid for the majority of 12 V batteries). So ideally the charge regulator should adjust the voltage threshold to the battery temperature.

For domestic solar systems, it should be assumed that the battery temperature is the same as the ambient temperature. It is thus enough that the regulator is equipped with a temperature sensor integrated into the regulating case, measuring the ambient temperature.

For solar systems greater than 500 Wp, battery temperature is measured continuously by a sensor attached to the battery casing with an electrical connection to the regulator.

Example 1:

If the ambient temperature is 35°C (often the case in some parts of Africa) and the end-of-charge voltage is 14.1 V at 25°C according to the manufacturer data, then the regulator will adjust the end-of-charge voltage to:

$$U_{\text{end-of-charge}} = 1411 - 0.018 \times (35 - 25) = 14.1 - 0.18 = 13.92 \text{ V}$$

For the sites where the temperature is always close to 25°C during the day (Democratic Republic of Congo, Rwanda, Uganda), the automatic offsetting of temperature is not necessary. On the other hand, in the Sahel countries, temperature compensation is strongly recommended.

4.2.5 Boost charge function

Some regulators have a function called "*Boost"* charge or "equalization" charge.

This function helps to increase the life of the battery by provoking a 'stirring' of the electrolyte; this helps to avoid stratification and also eliminates some sulphatation of the battery lead plates. When there is a *Boost* function, the charging thresholds are increased from 14.1 - 14.5 V up to 15 V.

This « boost » charge is activated according to the type of regulator: it can be done

- manually by the user or the technician, by switching it on,
- automatically, each time the regulator cuts off the loads due to over-discharge voltage, or
- automatically on a monthly basis (on large regulators).

Important : The « boost » or « equalization » charge function should be deactivated for sealed batteries (as it consumes electrolyte, that cannot be replaced).

4.2.7 Manufacturing and repair of regulators

Most types of regulators are quite difficult to repair. In some cases, the electronic components are not even accessible as they are moulded into the mass. Furthermore, it is almost impossible to get the electronic diagrams of the regulators. Manufacturers want to protect their designs to avoid poor ‘copies’ by their competitors.

A charge regulator can be made locally, but one should be extremely careful with designing one’s own regulator. As the regulator is the brain of a PV system, its proper functioning determines the performance and life of the complete system. For example, if a regulator has wrong or fluctuating thresholds (e.g. cutting-off the panel before the battery is fully charged) because the quality of its electronic components is mediocre, this will definitely damage the battery prematurely, while ironically, it should be the regulator that protects the battery and extend its lifetime.

It is strongly advised to use only well tested and proven designs.

When a regulator is damaged, it is best to replace it by a new one rather than trying to repair it, unless the expertise is readily available.

4.3 Types of regulator

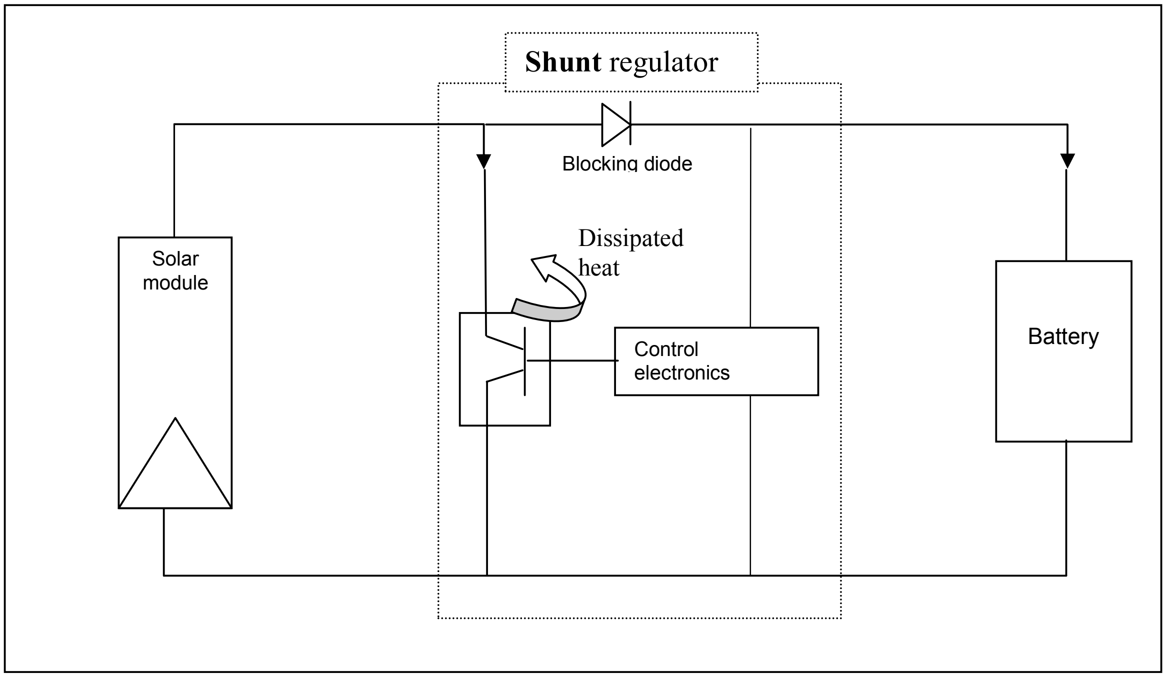
Nowadays, most regulators for small solar systems are made of solid state electronic components only (static components). There are no moving parts (no relays), hence they make no noise when the unit is in operation.

However, there are still some regulators which use relays (i.e. electro-mechanical switches). These are easily recognizable because you can ‘hear’ a small noise or click when the relay disconnects the panel and when the battery is full.

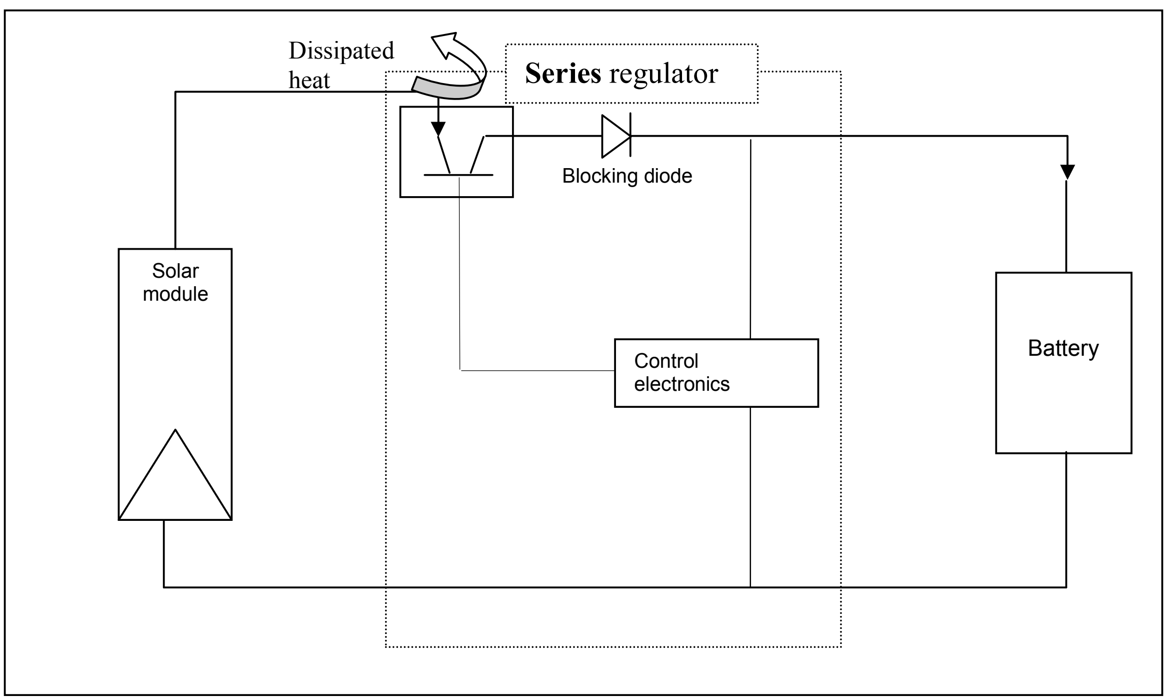
Some regulators, usually the cheapest ones, do not offer protection against over-discharging of the battery. Watch out for these.

4.3.1 Series and shunt regulators

There are two main types of solid state regulators: shunt and series. The simplified electrical diagrams below demonstrate both types of regulator, as far as the battery over-charge protection is concerned.



When the battery approaches a 100% state of charge, shunt regulators divert the excess current away through a power transistor to prevent over-charging of the battery. The power generated by the solar module is dumped into a power transistor heat sink. Shunt regulators can become warm or even hot when the battery is fully charged, especially around noon with full sunshine.



In this series regulator, the power transistor resistance increases when the state of charge of the battery is approaching 100%. When the battery is fully charged, the power transistor is like an open switch. When the battery is fully discharged, the power transistor acts like a closed switch.

4.4 Quality control when choosing and purchasing regulators

1. Always analyse the technical specifications and check for:

• **Maximum current accepted from the PV panel**	Check that this current is 25% higher than the Isc of the panel of your system.
• **Maximum current deliverable to the load**	Check that this current is 50% higher than the maximum current drawn by the loads of your system when they are all switched ON.
• **Low battery voltage indicator**	Check that this feature exists.
• **Solar charge indicator**	Check that this feature exists.
• **Voltage threshold for charging**	Check that they are compatible with the type of battery you will be using in your solar system
For an open or 'car' battery:	e.g. between 13.1 and 14.7 V
For a sealed battery:	e.g. between 13.1 and 14.1 V
• **Voltage threshold for discharge**	Check that they are compatible with the type of battery you will be using in your solar system.
For an 'open' car battery:	e.g. between 10.5 and 11.9 V
For a sealed battery:	e.g. between 11.4 and 11.9 V
• Reconnection voltage threshold / reset	e.g. 12.8 V
• Operating nominal voltage	e.g. 9 V to 30 V
• Maximum Voltage drop between array and battery (at the regulator level)	e.g. 0.1 V (this should be as small as possible)
• Maximum Voltage drop between battery and load (at the regulator level)	e.g. 0.05 V (this should be as small as possible)
• Maximum internal power (or current) consumption of the regulator unit	e.g. a few mA.
• Temperature compensation (integrated)	- 0.024 V / degree above 25 degrees C
• Electric protection (with fuses or electronic protection)	Check the electrical protection. If not available, it will be necessary to buy a fuse box to protect the load circuit and an in-line fuse to protect the cables between the battery and the regulator.

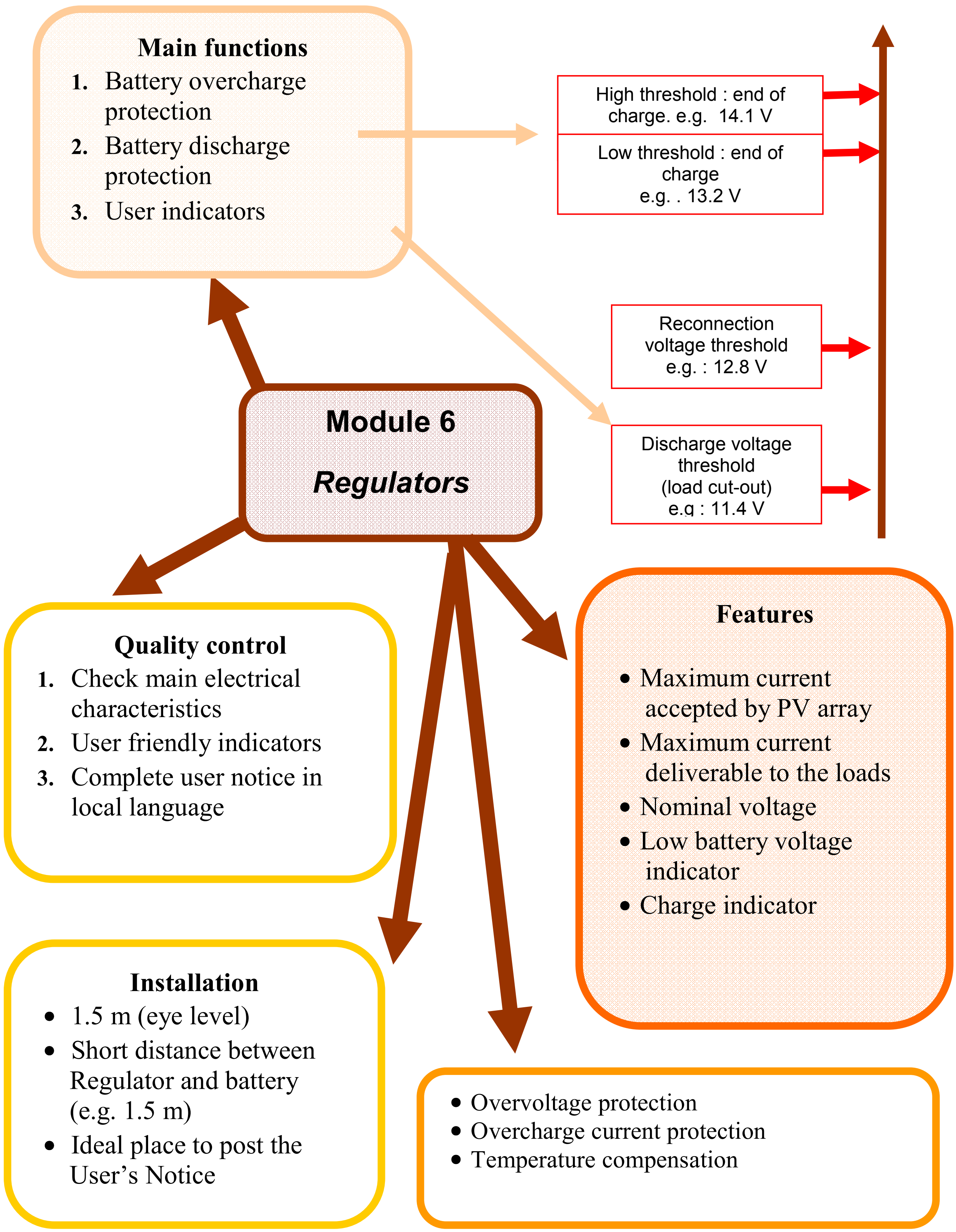
2. Check whether the unit is user friendly: is the information given by the indicators easily understandable by a client, is it confusing?

3. **Ask about warranty protection;** good quality regulators can have warranties for up to 2 years. Most often however they are for one year.

4. Ask about the track record of the regulator: has the retailer had any complaints about the unit (this will give an indication of expected reliability, long life)?

5. Ask to see the full installation, operation and maintenance instructions.

6 Summary diagram



7 Assessment and feed-back

This section is for the Trainers to ensure that Trainees have understood the main concepts presented in this module. The concepts taught here are fundamental for proceeding to the following modules. As such, the trainer needs to assess how well trainees have understood the concepts taught here.

Suggested activities to be carried out in teams, individually or as an individual session:

- Briefly describe the main functions of a regulator.
- Draw an electrical circuit (two wires) of a solar system with the regulator, solar module, battery, loads and fuses.
- Describe in detail the main electrical characteristics of a regulator.
- Give the approximate values of voltage threshold for overcharge protection.
- Give the approximate values of voltage threshold for over-discharge protection.
- Give the re-connexion threshold voltage (reset) to extend the lifetime of the battery.
- Calculate the end-of-charge voltage threshold of a regulator under the following conditions: ambient temperature 40°C, regulator given with an end-of-charge voltage threshold of 14.3 V at 25°C with a temperature compensation of -18 mV / °C.
- Make a list of the quality control issues when purchasing a regulator.

Important note : if the training course is to result in the qualification of trainees for a certain level, it is suggested to give similar exercises as those that will be given on the examination day.

This has the advantage of preparing the trainees for the final qualification examination and evaluation[2].

[2] Examinations should not be conceived to lead to failure: they should be a true measure of knowledge acquired.

MODULE 7 : Batteries

1 Objectives

The learning objectives of this module are;

- various battery technologies,
- the main technical characteristics of batteries,
- how best to charge batteries,
- how to size a battery and
- quality control when choosing and purchasing batteries.

2 Module duration

6 – 8 hours

3 Necessary teaching equipment

Description	**Qty (minimum)**
Sealed lead-acid battery 4 Ah / 6 V (new)	2
Sealed lead-acid battery 4 Ah / 6 V (used)	2
Sealed lead-acid battery 7 Ah / 12 V (new)	1
Sealed lead-acid battery 7 Ah / 12 V (used)	1
Car battery 35 to 75 Ah (new)	1
Car battery 35 to 75 Ah (used)	1
Solar battery bank (12 units of 2 V, 200 Ah) – (used or faulty battery bank)	1
Solar calculator	5
Multimeters	5
A set of cables and accessories	1

4 Content

4.1. Introduction

Batteries are the most common cause of system failure. To limit system failures, batteries have to be properly chosen, installed and maintained to ensure optimal functioning.

A battery is different from a dry-cell (used to power small radios), because it can be recharged many times.

Battery technology has not yet reached a desirable point. Batteries are still voluminous and heavy in relation to the limited amount of energy they can accumulate.

The batteries used in solar systems are lead-acid batteries. Other types exist, but they are either for specialized purposes or still under development and so are not yet readily available for solar system uses (e.g. Ni-Cd (nickel-cadmium), Ni-Mh (nickel-metal hydride), lithium ion, etc.).

4.1.1 Operating principles

A lead-acid battery consists of lead electrodes (negative plates in Pb) and lead oxide electrodes (positive plates of PbO_2) that interact with sulphuric acid in an electrochemical process which is *reversible*. This in turn results in a flow of electrons through the battery and into the load. The **electrolyte** is a solution of sulphuric acid in water (a highly corrosive liquid). The electrolyte becomes diluted as the state of charge decreases. Hence, a fully discharged battery contains a weak electrolyte solution.

Positive plate during discharge

$$PbO_2 + HSO_4^- + 3H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O$$

Negative plate during discharge

$$Pb + HSO_4^- \rightarrow PbSO_4 + H^+ + 2e^-$$

$$PbO_2 + 2H_2SO_4 + Pb \underset{\leftarrow\leftarrow \text{ Charge } \leftarrow\leftarrow}{\overset{\rightarrow\rightarrow \text{ Discharge } \rightarrow\rightarrow}{\rightleftharpoons}} PbSO_4 + 2H_2O + PbSO_4$$

(+ Plate) (Electrolyte) (- Plate) → **(+ Plate) (Electrolyte) (-Plate)**

- During charging several chemical changes take place: sulphuric acid ($2H_2SO_4$) is formed, lead is formed on the negative plates and lead oxide (PbO_2) is formed on the positive plates. Hydrogen and oxygen gases are also released; hence water is consumed.
- During discharging, the electrolyte becomes weaker. There is formation of lead sulphate on both plates.

4.1.2 Plate construction

In a lead-acid battery, the negative plates are made of powdered lead fixed on a conductor (electrode grid) support. The positive plates are made of lead oxide pastes dried onto an electrode grid to form a plate that holds the material. These plates act as a collection grid for the electrons that flow in the battery.

As pure lead and lead oxide are not strong enough, antimony, calcium and other substances are added to create lead-alloys which are stronger and, therefore increase the life of the battery.

- Antimony increases the *cycle life,* but on the other hand increases the distilled water consumption and self-discharge rate.
- Calcium generally allows a lower distilled water consumption permitting less frequent or maintenance-free batteries, but greatly reduces tolerance to deep-discharge.

Finally, the thicker the positive plates the better the *cycle life* when deep cycling. The positive plate thickness may vary from 1.5 mm to more than 6 mm depending on the type of battery. The choice of an appropriate thickness and chemical composition of the plates defines the performance of a battery.

Show trainees the plates of used car batteries and used solar batteries, as their casing is transparent.

4.2 Terms used to specify batteries

Manufacturers publish details of their batteries using specialised terms to characterize their products, so an understanding of their meanings is quite useful. Most importantly, understanding these terms is crucial to being able to size and choose an adequate battery.

4.2.1 Nominal or Rated Capacity (C) [unit Ah]

The capacity (C) indicates the amount of energy that can be drawn from the battery when fully charged, before it is completely discharged.

A water tank, for example, with a capacity of 8000 litres can hold at most 8000 litres. Similarly, a battery can only store a fixed amount of electrical energy, which is normally indicated on the outside of the battery by the manufacturer. This is known as nominal or rated capacity.

However, nominal capacity is just indicative. The actual capacity depends on**:**

Discharging current	**C** decreases when the discharge current increases
Years of use	**C** decreases when the battery is old
Maintenance	**C** decreases if the battery is overused or when maintenance is not done properly
Temperature	**C** increases with temperature up to 45°C, but decreases if > than 45°C

A **battery's rated capacity (C)** is the total quantity of electrical charge (i.e. current x time) in Ah (ampere-hours) that can be drawn from a fully charged state at a specified discharge rate and electrolyte temperature before the voltage falls to a specified cut-off voltage.

The rated capacity should always be specified using the combined factors: discharge rate, temperature and cut-off voltage (e.g. a lead-acid battery of 100 Ah at C/10, 25°C and 10.8 V cut-off voltage).

The rated capacity (C_n) is the electrical quantity supplied by the battery producing a current I_n during *n* hours:

$$C_n = I_n \times n$$

For example, a 120 Ah C_{10} battery means that this battery is able to supply 120 Ah for a 10 hours duration, with a current I_{10} of 12 A.

$C_n = I_n \times n$ → $C_{10} = I_{10} \times 10$ hours → 120 Ah = 12 A x 10 hours

Example (from manufacturer data)

Solar Bloc S Battery	**C_{12}**	**C_{100}**	**C_{120}**
Rated capacity C_n	61 Ah	70 Ah	71 Ah
Discharge current $\mathbf{I_n}$	$I_{12} = C_{12} / 12 = 5.08$ A	$I_{100} = C_{100} / 100 = 0.7$ A	$I_{120} = C_{120} / 120 = 0.59$ A
Discharge duration **n**	61 / 5.08 A = 12 hours	70 / 0.7 = 100 hours	71 / 0.59 = 120 hours

The same battery can have different capacities according to the discharge rate.

Ask trainees to calculate the discharge current for a 100 Ah C_{20} battery to produce 100 Ah.

Answer: $C_{20} = I_{20} \times 20$; $I_{20} = C_{20} / 20 = 100 / 20 = 5$ A (the battery will supply 5 A during 20 hours).

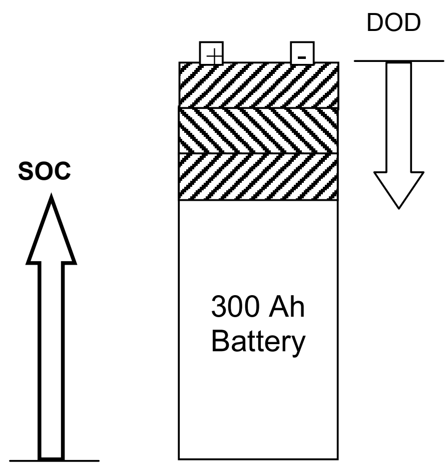
Ask trainees measure the capacity of a 7 Ah battery, with a small discharge rate (ex: 0.66 A), then with a high discharge rate (2 A). For each test, proceed as follows:
Step 1: Fully charge the battery
Step 2: Measure the current supplied every minute until the voltage is 10.5 V

Compare the measured capacities with the rated capacity on the battery label and draw conclusions.

4.2.2 State of charge (SOC) [unit %]

SOC is the amount of charge left in the battery expressed as a percentage of the rated capacity (i.e. 100% is full charge, 50% is half charge).

If a 300 Ah battery has a **SOC** of 70 %, then it holds only 210 Ah (i.e. 300 Ah x 70 %).



Examples:
If a 100 Ah C_{100} battery has a SOC of 50 %, it can supply 50 Ah with a 1 A current.

4.2.3 Charging current I_n [unit A]

The **charge rate** is the current at which a battery should ideally be charged.

The **charging current** is the electric current supplied to a battery for charging. As a water tank will take more or less time to fill depending on the rate at which water enters it, the amount of time required to completely charge a battery depends upon the size of the current at which it is being charged (i.e. the charge rate).

$$C_n = I_n \times n \quad (n = \text{time}) \quad \rightarrow \quad C_{100} = \mathbf{I_{100}} \times 100 \text{ hours}$$

The time needed to charge a battery depends on:

Charge current	The higher the current, the faster the charge. Beware: Charging a battery at too high a rate can cause permanent damage to the battery.
SOC	If the SOC is low, the duration of charge will be long

Rule : It is necessary to respect the ideal charging current. As a general rule, most batteries can be safely charged with a current equal to one tenth of the rated capacity (i.e. C/10). For example, a 50 Ah battery can be safely charged at 50 Ah / 10 = 5A

Ask trainees if it is safe to charge a 7 Ah / 12 V battery with a 10 Wp module?

Answer: the Isc of the 10 Wp module is around 0.62 A, hence it will never give the battery more than 0.62 A. The charge rate will be at most: 7 Ah / 0.62 A = 11. So this charge current is safe as it is less than C/10 = 0.7 A.

Repeat the same question as above but with a 50 Wp module charging the same battery.

4.2.4 Battery charge/discharge efficiency [unit %]

Charge/discharge efficiency is the ratio (expressed as a percentage) of the amount of energy used by the loads (e.g. lights at night) to the amount of energy needed to recharge the battery fully over a complete cycle (supplied by the solar panel during the day).

$$\text{Charge/discharge efficiency (\%)} = \frac{\text{Daily needs (Ah)}}{\text{Energy supplied to recharge the battery (Ah)}}$$

In practice, it means that if a solar system battery has supplied 50 Ah during the night, the PV module will have to supply 60-70 Ah to the battery to be fully charged again. Then it can be able to deliver 50 Ah again the following night.

4.2.5 Self-discharge [unit % / month]

Self-discharge refers to the charge lost when a battery is not used over a period of one month; it is expressed as a percentage of the initial state of charge.

If left unused and uncharged, all batteries slowly lose their charge, but some types of battery self-discharge faster than others.

Self-discharge rates vary with:

Battery type	From 3% to 30% per month
Temperature	The self-discharge rate increases with temperatures greater than 25°C
Purity of the electrolyte	The self-discharge rate increases with poor quality electrolyte or poor quality distilled water is added to a battery
Years of service	The self-discharge rate increases with the age of the battery

Self-discharge rate (%) as a function of temperature and years of storage
(case of stationery tubular batteries filled with electrolyte)

	Storage temperature					
Storage time	20°C	25°C	30°C	35°C	40°C	45°C
1 month	2.5	3	4.5	7	10	14
2 months	4.5	6	9	13	19	28
3 months	6.5	8.5	13	19	28	41
4 months	8	11	17	25	36	53
5 months	10	14	20	30	45	65
6 months	12	16	24	36	53	77

Reference: Total Energie

When batteries with electrolyte are left uncharged for a long time (i.e. several months) they will be permanently damaged (permanent loss of capacity, not recoverable). **Batteries should always been maintained and stored in a good state of charge**.

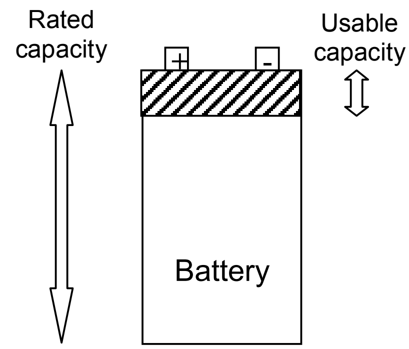
Note: *To explain the concept of self-discharge, one can compare a human being with a battery. If a person sleeps for days and days, hence not working, he or she will still need to eat and drink. If they are not offered food and water, they will fall sick and eventually die. It is the same for a battery even if no current is given to a load. If it is not fed regularly, it will die. Batteries consume some energy 'internally', hence they need regular recharging.*

4.2.6 Usable capacity (Cu) [unit Ah]

The Usable capacity (Cu) of a battery is equal to the daily electricity need.

Cu = Daily need

The usable capacity of a battery is the fraction of the rated capacity that is used for each *cycle* (usually shallow cycles) to ensure the battery will have a reasonable cycle life. The usable capacity of the battery is set as equal to the daily need for electricity to prevent battery over-discharging.



Ask trainees to calculate what should be the usable capacity of a battery if the daily energy need for a PV system was 360 Wh.

Answer: 360 Wh / 12 V = 30 Ah. (Beware that this is not the capacity that one will consider buying for the system. We will see later that one should consider buying a much larger capacity battery).

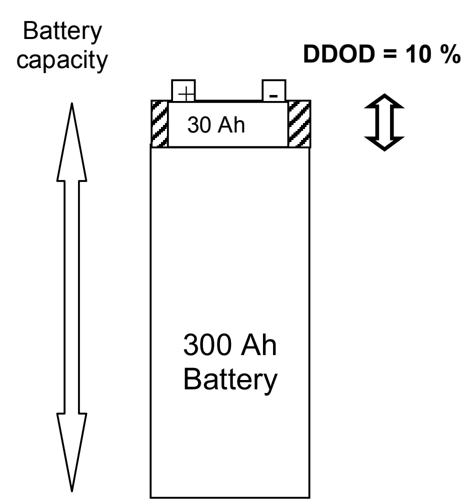
4.2.7 Daily depth of discharge (DDOD) [unit : %]

This a very useful ratio to express what is happening daily to the battery in a solar system

$$\text{DDOD (\%)} = \frac{Cu}{Cn} = \frac{\text{Daily needs (Ah)}}{\text{Battery capacity (Ah)}}$$

Example:
If the battery has a capacity of 300 Ah C_{100} for a solar system where the daily need is 360 Wh, that is 360 Wh / 12 V = 30 Ah,
Then the DDOD is calculated as:

DDOD = 30 Ah / 300 Ah = 10 %.



4.2.8 Depth of discharge (DOD) [unit: %]

This is the ratio (expressed as a percentage) of the usable capacity (daily needs) multiplied by the system's autonomy to the rated capacity of the battery.

$$\text{DOD (\%)} = \frac{\text{Daily needs (Ah) x Autonomy (days)}}{\text{Battery rated capacity (Ah)}}$$

Autonomy:

Autonomy refers to the number of days that the solar system must continue to supply power without sunshine to recharge the battery, without discharging the battery below the maximum depth of discharge (e.g. 3 days of bad weather).

DOD and cycles

A cycle refers to the period of time during which a battery is charged and then discharged. The lifespan of a battery is measured in the number of cycles it will perform over time.

- When the DOD is greater than 50%, the battery is said to have ***'deep cycles'***.
- When the DOD is less than 20 - 30%, the battery is said to have a ***'shallow cycles'***.

Shallow cycling of batteries is always preferable as shallow cycles extend battery life.

Relationship between DDOD and DOD

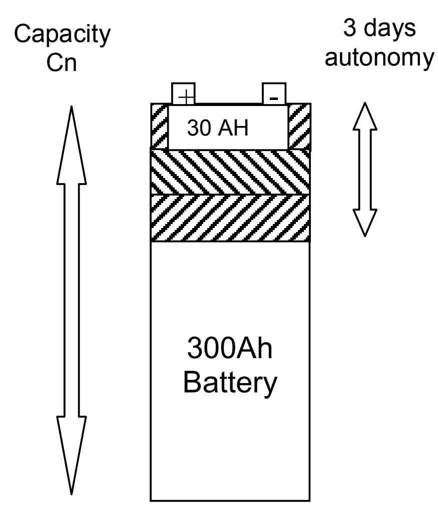
$$\text{DDOD} = \frac{\text{DOD}}{\text{Autonomy}}$$

An example of battery sizing:

A client needs 4 lamps (9 W) during 10 hours each night. His daily needs are 9 W x 4 x 10 hours = 360 Wh. The **usable capacity** is 360 Wh / 12 V = 30 Ah.

If the chosen **DOD** is 30 % and the **autonomy** is 3 days, then the required battery capacity will be:

Cn = (30 Ah x 3 days) / 30 % = 300 Ah.



4.2.9 Cycle life

The lifespan of a battery is measured in the number of cycles it will perform over time; this is also referred to as the cycle life of a battery.

Cycle life is the number of times (i.e. cycles) a battery can be charged and discharged before it loses more than 20% of its rated capacity permanently.

Example 1:
In the case of a PV system charging a battery, the battery will be recharged every *day* when the sun shines and discharged every night to power lights; in this case the cycle duration is 24 hours (1 day). If, after 2 years (720 days or cycles), the battery capacity has fallen to just less than *80%* of its rated capacity, its *cycle* life will be 720 cycles.

Example 2:
If the same battery was taken to the nearest town for recharging from the mains once a week, then it would be on a weekly cycle. If this battery lasted one year and then its capacity falls to just less than 80% of its rated capacity, then its *cycle* life would be 52 cycles.

Cycle life of batteries varies with:

Battery type	Whether it is a car battery or a solar battery
Daily depth of discharge	Low daily depth of discharge (DDOD) will increase cycle life
SOC before cycling	If the battery is never fully charged before being discharged, the battery lifetime will be shortened
Temperature	If the temperature is often above 35°C, the cycle life will be reduced.

Because of the factors above, the cycle life is always specified using the combined factors of: depth of discharge (DOD), rate of discharge (C/n, n is usually equal to 10 or 100) and temperature (e.g. 1000 cycles at 80% DOD, C/10 and 25°C).

4.2.10 Vented (unsealed) and sealed lead-acid batteries

Traditional designs of lead-acid batteries (i.e. vented or unsealed) need occasional **replenishment with distilled water** to maintain the correct strength of dilution of the acid as some water (hydrogen and oxygen) will be lost with normal use. Modern designs of lead-acid batteries, however, are sealed and preserve the electrolyte in a 'dry' form, as in a primary dry cell.

Display various types of lead-acid batteries and ask trainees which ones are sealed and unsealed.

4.3 General characteristics of lead-acid batteries

Lead-acid batteries are the most commonly used type of battery in solar systems.

4.3.1 General characteristics

- A 12 V battery is made of 6 elements in series: the nominal voltage of each element is 2 V.

- Traditional designs of lead-acid batteries (i.e. vented batteries) need occasional **replenishment with distilled water** to maintain the correct strength of dilution of the acid as some water (hydrogen and oxygen) will be lost with normal use.

- Sealed lead-acid batteries preserve the electrolyte in a 'dry' form, as in a primary dry cell. They have a greater reserve of electrolyte than vented batteries. They are considered maintenance free batteries, but they do consume some water.

- Battery lifespan is lengthened if the daily discharge (DDOD) is only a small percentage of battery capacity. For example for a car battery, if the DDOD is 50 %, then the lifespan of the battery may be 6 only months or 182 cycles. But if the DDOD is only 30 %, then lifespan may be increased to 2 years or 730 cycles.

- Charge / discharge energy efficiency is between 65-90 % with an average value of 75 %.

- Electrolyte density is often between 1.28 for car batteries and 1.24 for solar batteries (initial electrolyte density when filled or when the battery is 100 % charged).

- Battery life diminishes considerably as temperature increases. Consequently, batteries should be installed in places where the temperature is around 25°C wherever possible.

- Battery capacity also varies with temperature. Capacity is reduced by 1 % per °C at temperatures less than 25°C, and is increased by about 0.5 % per °C at temperatures greater than 25°C up to 40°C (see **page 32 of the Paper Tool**).

4.3.2 Charging techniques for Lead-acid batteries

Ideally, Lead-acid batteries need to be recharged in a carefully controlled manner. Nowadays, most solar regulators, especially those using solid state components (with no relays) provide a charge well suited to Lead-acid batteries.

- Rate of charge (charging current): should be relatively high at the beginning of the charge (e.g.: a C10 current with a voltage of 14.3 V at 30°C), then the charging current needs to be tapered off as the battery approaches full charge. For example, a 100 Ah C_{10} battery could be charged with an initial current of 10 A, then 5 A and finally 1 A.

- Temperature influence: The final charging voltage decreases linearly with battery temperature (typically 15.2V at 0°C and -0.03V/ °C above 0°C, i.e. 14.3V at 30°C).

- Equalization charge: this is an extended charge at low current levels (called a trickle or equalization charge) to equalize the voltages of all cells. This is necessary because sometimes one cell of a lead-acid battery may not accept its charge at the same rate as the others and so it is left only partially charged while the others are fully charged. In this case the partially charged cell may become over-discharged and eventually fail prematurely before the other cells. This type of charge is also known as a Boost charge (see **Module 6: Charge regulator**).

- **"Formatting" a battery**: When a vented lead-acid battery is first put into service (e.g. when it is filled with electrolyte for the first time), it needs to be fully charged (100 %) to ensure the "formatting" of the plates. This will ensure an increased lifetime of the battery.

4.3.3 State of charge (SOC) / electrolyte density / Open circuit voltage

These three parameters are linked.

The state of charge of a battery can be evaluated in two ways:
Refer to **pages 33 and 73 of the Paper Tool.**

An example of the graph State of Charge / Uoc and electrolyte density is given.

The battery SOC can also be determined by discharging a battery and comparing the measured capacity to the rated one. This method is only feasible in a workshop setting, not in the field.

4.4 Most common types of lead-acid battery

Lead-acid batteries can be classified into several categories:

1. Car batteries (car or truck/lorry)
2. Solar batteries (plane plates)
3. Traction batteries
4. Solar stationery batteries (tubular planes)
5. Sealed batteries

4.4.1 Car batteries

Automotive batteries have been designed for starting cars, trucks and lorries.

The cell design in a car battery is optimized to deliver heavy currents for short periods of time (starting a car requires 50 to 100 A for a few seconds). Car batteries have large areas of thin plates which are poorly suited to supplying smaller currents for many hours before being recharged, as is required for most domestic PV applications.

A typical car battery will only withstand about 20 to 30 deep discharge cycles before it becomes completely useless.

Car batteries are easily damaged if left discharged for any length of time. This is due to the fact that in normal use in cars, every time the battery is discharged it is immediately recharged by the alternator.

Despite their relatively short lifespan when used in domestic PV applications, automotive batteries have the advantage that they are usually the least expensive batteries on the local market when compared other batteries of similar rated capacity (typically 35 to 200 Ah).

They are often locally produced and are widely available and, to some extent, repairable (i.e. one or several damaged cells can be replaced in local workshops or at the local factory).

4.4.2 Solar batteries with plane plates

These are essentially ‘improved’ car batteries. They have the same external shape as car batteries, but they have thicker plates (to increase cycle capacity) composed of alloys with low antimony levels which lower distilled water consummation, internal corrosion and self-discharge. Their weakness: they do not have large reserve of electrolyte within them.

4.4.3 Traction batteries

These batteries are essentially designed to power electric vehicles. They can withstand deep discharges but they must be recharged as quickly as possible. They consume great quantities of distilled water. They are used on certain solar systems as the cost / quality ratio is excellent.

4.4.4 Stationary solar batteries

These batteries are designed for solar systems. Distilled water consumption is low. They may also be equipped with recombination caps to further reduce distilled water consummation. Normally, these batteries have a transparent casing and a large reserve of electrolyte which facilitates maintenance and reduces its frequency.

Stationary solar batteries are expensive however and are only available through photovoltaic material suppliers.

4.4.5 Sealed batteries

Sealed at the factory, they do not leak or spill, so they are easily transported and do not require electrolyte top-up when put into service.

The electrolyte is either absorbed onto a 'glass mat' or is in a gelled form so that it cannot be spilled and contains chemicals that absorb the hydrogen and oxygen that are produced. The recombination process is not 100% efficient and so some gasses are emitted, but only 1% of that of an unsealed battery. The gasses are evacuated through a regulated safety valve, but the battery contains enough electrolyte for its entire life and therefore does need maintenance. Hence, they are often referred to as a ‘maintenance-free’ battery.

These batteries exist with plane or tubular plates. Their performances vary accordingly.

Overall, a sealed battery is likely to have a shorter life than a well maintained unsealed solar battery, but will obviously last longer than a poorly maintained unsealed solar battery (i.e. if no one tops up distilled water in the unsealed solar battery).

The main disadvantages of sealed lead-acid batteries are:

- They need regular recharging to prevent sulphate build-up leading to permanent damage during transport and storage prior to installation. Batteries would typically be recharged in storage *every* 6 months. This can present further problems in countries where high ambient temperatures accelerate self-discharge.
- They have poor performance characteristics at high temperatures, so they should not be used in hot climates. They age fast when the temperature is above 25 degrees C.
- They are among the most expensive types of batteries.

4.4.6 Comparison of lead-acid batteries

	OPEN BATTERY (AT 20°C)			
	Car or truck battery	**Solar battery**	**Traction battery**	**Stationary solar battery**
Type of pates	Thin plane	Thick plane	Tubular	Tubular
Electrolyte density	1.28	1.24 to 1.28	1.26 to 28	1.24
Number of cycles				
DOD 20%	800	2250	3000	3500
DOD 30%	700	1900	2000	2250
DOD 50%	200	750	1200	1350
DOD 80%	60	150	900	750
Distilled water consumption	Average	Average to low	High	Low
Self-discharge	Low	Low	High	Low
Electrolyte reserve	Low	Low	Low to average	High

Indicative values based on manufacturers' data.

	SEALED BATTERY (at 20°C)		
	Battery (AGM)	**Battery (gel)**	**Solar battery (gel)**
Type of plate	Thick plane	Thick plane	Tubular
Type of electrolyte	AGM	Gel	Gel
Number of cycles			
DOD 20%	1900	4500	5000
DOD 30%	1600	3000	3500
DOD 50%	700	1500	2500
DOD 80%	375	900	1300
Distilled water consumption	Average to low	Very low	Very low
Self-discharge	Low	Very low	Very low
Electrolyte reserve	Low	Gel electrolyte with internal recombination of oxygen	Gel electrolyte with internal recombination of oxygen

Indicative values based on manufacturers' data.

Warning: Consult manufacturer's instructions concerning ambient temperatures of operation site. For example, an increase of 10°C can reduce performance of sealed batteries up to 50 %.

4.5 Association of batteries in series or in parallel

The association of batteries is best demonstrated through the practical exercises explained here.

Ask trainees to connect two, then three, 12 V batteries in parallel and connect an 8 W lamp to them. Measure the voltage and the current given by each battery. Also measure the voltage and current of the lamp.

Conclusion: The Current adds up to that drawn by the lamp, but the voltage remains the same in each battery.

U = U of battery 1 = U of battery 2 = U of battery 3
I drawn by lamp = I battery 1 + I battery 2 + I battery 3

The total battery capacity is the addition of each individual battery capacity.

Have trainees connect two 6 V batteries in series, connect an 8 W lamp to them and measure the voltage and the current given by each battery. Also measure the voltage and current of the lamp.

Conclusion: The Voltage adds up to that of the lamp, but the current is the same from each battery.

U = U of battery 1 + U of battery 2
I drawn by the lamp = I battery 1 = I battery 2

The total battery capacity = capacity of battery 1 = capacity of battery 2.

4.6 Notion of battery sizing

Battery sizing depends on the daily load (i.e. the client's energy needs), the length of time the system is required to operate without sunshine (the Autonomy), and the DOD. A full example of sizing procedure is given in **Module 9.**

For now, it is important to know that:

- an undersized battery will be cheaper to buy, but will be exposed to deeper cycles and so will have a shortened life;
- an oversized battery will be more expensive and will rarely be fully charged by the PV panel, therefore becoming sulphated, and so, have a shortened life.

The proper sizing of a battery is always about finding the right compromise.

4.7 Safety precautions for battery installation and maintenance

▲ **Warning: Do not let metal objects connect between the positive and the negative terminals of a battery.**

Shorting the negative and the positive terminals will cause sparks and there is risk of explosion due to the hydrogen gas. If the short-circuit lasts for any length of time, both the battery and the wires will get very hot. This can start a fire or cause the battery to explode.

While working near battery connectors, always place a piece of cloth over the connectors to avoid any electrical contact with metallic pieces.

▲ **Be very careful when filling a battery with electrolyte (when putting a new battery in service or when adding water to maintain the level of electrolyte).**

Batteries contain acid, which is very dangerous if splashed into the eyes. This can be prevented by wearing glasses, plastic gloves and being very careful. If the acid is splashed into the eyes, force the eyes open and pour plenty of water into the eyes immediately. Seek advice from a doctor immediately.

Battery acid is also harmful to skin and clothing. If acid gets splashed on your skin or clothes wash immediately, with plenty of water. Finally, always wash your hands (and your tools: funnel, hydrometer, etc.) after handling batteries.

▲ **Take care when transporting or carrying batteries.**

When carrying batteries, place your hands under the battery (unless it has handles) to prevent it from slipping and dropping on the ground. Dropping the battery could damage the plates and cause internal shorting, which could cause the battery to explode. Keep the battery upright when it is being transported.

▲ **Do not cause sparks or smoke around batteries.**

Batteries produce a mixture of oxygen and hydrogen which explode when ignited. Hence, do not smoke and avoid sparks or welding around batteries.

▲ **Keep batteries in a battery box whenever possible. Avoid placing them directly on the floor.**

5 Quality control when purchasing batteries

1. Always double check your sizing.

If you are buying a battery from a PV supplier, ask him to double check your battery sizing. If large differences exist and remain obscure, discuss them with the supplier. Quite often, the supplier may be willing to supply you with a smaller size battery cheaper for him to sell. However, the DDOD will be higher and hence, the life of the battery will be shorter.

2. Go through this table with the battery supplier

• **Rated (storage) capacity C_{10}(Ah)**	Ask at which rate of discharge the capacity is given (e.g. 100 Ah at C/100)
• **Nominal voltage (V)**	e.g. 2 V, 6 V or 12 V
• **Type of technology**	e.g. vented lead-acid or sealed e.g. type of batteries: solar, truck battery, etc.
• **Cycle life versus daily depth of discharge (DDOD)**	Ask for the cycle life value at several DOD (ask for a diagram)*
• **Electrolyte specific gravity / open voltage / state of charge**	Ask for the relationship between specific gravity and state of charge (SOC)
• **Manufacturing date / date of last charging for sealed batteries**	
• **Charging thresholds / discharging thresholds voltage**	Crucial to select a matching charge regulator
• Consumption of distilled water (litres / month)	
• Self-discharge (% / month)	
• Maximum charging current / discharging current	Ideal charging current – procedure for putting the battery into service
• Energy efficiency (during charge and discharge)	Usually difficult to obtain

*For car batteries, this information is almost impossible to get.

3. Calculate the price in local currency per Ah (or in € / Ah) and compare with other prices around.

It is only possible to compare prices if the battery capacity for each battery you want to compare has been given for a similar discharge rate.

In general, the price in € / Ah should decrease with the increasing size (i.e. capacity) of the batteries. It is always advisable to buy a large single battery rather than several small ones to meet the required capacity (e.g. a 200 Ah / 12 V battery is preferable than 2 batteries of 100

Ah / 12 V). Automotive batteries for trucks and buses are slightly better than the car batteries because their thicker plates are designed to withstand deeper cycling.

4. Ask if the supplier is giving any warranty and ask the implementation details.

The terms of the warranty may be contingent on;

- filling with electrolyte and first use of the battery in the supplier's workshop or,
- an obligation to use electrolyte supplied by the supplier.

5. Ask for the complete set of installation, operation and maintenance instructions.

6. Do not forget to buy sufficient electrolyte to fill the battery.

It is always best to negotiate buying the electrolyte from the battery vendor, rather than from another supplier. Failure to do this will allow the battery manufacturer to claim that the battery is faulty because it has been filled with the 'wrong electrolyte'.

7. Do not forget to purchase distilled water for maintenance (a one year supply).

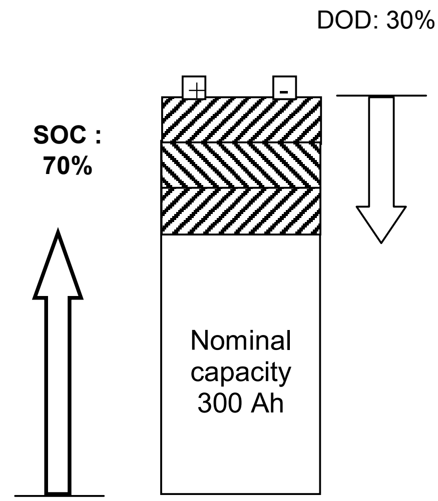
8. Finally and in some cases only, have the battery filled and top-charged at the battery vendor's shop.

This gives you the assurance that the battery is working. However you will have to transport this battery to the installation site as quickly as possible (to avoid self-discharge) and without spilling the electrolyte.

6 Summary diagram

State of charge (example)

- SOC = 100% →Uco = 12.8 V and density = 1,28
- SOC= 20% →Uco = 11.9V and density = 1.12



- Capacity (Ah) C_{10}
- Nominal voltage (2 V or 12V)
- **Lifetime decreases with DDOD**

Module 7

Batteries

Technology

Open or sealed batteries (lead-acid)

Installation

- **Formatting the plates before putting into service**
- Ventilated battery box
- Labelling with installation date
- Plan for distilled water : maintenance

Quality / best buy

1. Choose the capacity in C_{10} (e.g. : 100Ah C_{10})
2. **Electrolyte density suited to the battery**
3. Quality distilled water
4. End-of-voltage threshold appropriate to the regulator

Battery capacity = Daily needs x AUT / (U x DOD)

7 Assessment and Feed-back

This section is for the Trainers to ensure that Trainees have understood the main concepts presented in this module. The concepts taught here are fundamental for proceeding to the following modules. As such, the trainer needs to assess how well trainees have understood the concepts taught here.

Suggested activities to be carried out in teams, individually or as an individual session:

- Define the following terms; Rated Capacity, State of Charge, Depth of Discharge (DOD), Discharge rate and Cycle life.
- Comment on the influence of DOD on the lifespan of a battery.
- Comment on the influence of Discharge rate on the battery Capacity.
- Draw an approximate graph with the State of Charge, Electrolyte density and Open circuit Voltage of a battery.
- Describe two ways to measure the State of Charge of a battery.
- List the principle safety precautions for battery installation and maintenance.
- List the key parameters of quality control when purchasing a battery.

Important note : if the training course is to result in the qualification of trainees for a certain level, it is suggested to give similar exercises as those that will be given on the examination day.

This has the advantage of preparing the trainees for the final qualification examination and evaluation[1].

[1] Examinations should not be conceived to lead to failure: they should be a true measure of knowledge acquired.

MODULE 8 : Loads, inverters, cables and accessories

1 Objectives

The learning objectives of this module are;

- how to choose electrical loads,
- how to choose and size cables,
- how to choose fuses or circuit breakers to protect small PV systems from short-circuits,
- main characteristics of DC-DC adapters and converters,
- main characteristics of inverters (DC-AC) and
- quality control when purchasing appliances and cables.

2 Module duration

4-8 hours

3 Necessary teaching equipment

Description	**Qty (minimum)**
Lamp 8 W / 12 V	1
Lamp 13 W/ 12 V	1
Cable 2 x 2.5 mm2 (meters)	10
Fuses (of various calibre/ size)	5
Battery 7 Ah 12 V	1
Battery 50 to 100 Ah 12 V	
DC-DC converter	2
Inverter DC-AC	1
Radio or radio cassette players (4 to 6 cells 1.5 V)	1
TV and VCR (AC appliances)	1
Lamp 50 to 100 W 230 V	4
Multimeters	4
A set of cables and accessories	1

4 Content

4.1. Loads and appliances

Loads and appliances are used by the clients. They represent the client's energy needs. For that reason, many examples of loads have been given in **Module 4, section 4.4.**

4.1.1 Nominal voltage

Loads can be appliances such as lights, radios, radio-cassette players and small TV sets (refer to a full list in **Module 4**). It is generally preferable that they be run directly from a 12 V DC supply or a 24 V DC supply.

If they cannot run on a 12 V, the system will need to be equipped with either an inverter for AC appliances, or a DC-DC adapter for some DC appliances.

In some cases, it is more economical to buy a new 12 V DC load, rather than buying an inverter to power the old AC load.

4.1.2 Nominal power

The power of the loads must be known before dimensioning and installing a solar system.

Nominal power is often labelled on appliances. If it is not known, it is essential to calculate it by measuring the intensity with an ammeter and multiplying the result by the voltage (refer to the examples in **Module 4**).

Always remember that in order to reduce the size and cost of a solar system, the following rules should be kept in mind.

Rules:

- **Choose appliances with the lowest power consumption for a given service (e.g. fluorescent lamps are preferable to incandescent bulbs).**
- **Choose 12 V or 24 V DC appliances.**
- **Appliances should be situated in places that suit the client's wishes but not too far from the battery / regulator so as to reduce cable lengths.**

4.1.3 Choosing lamps

In general, give preference to fluorescent or LED lamps rather than incandescent bulbs.

If a lamp will be lit only a few minutes every day, for example, in a bathroom or a corridor, then an incandescent lamp (i.e. a 5 or 10 W bulb) may be chosen rather than a fluorescent lamp (i.e. an 8 W tube). An incandescent light is often cheaper to buy and, as the lighting duration is short, it will not increase the system size in terms of module and battery sizes.

In practice, 8 W or 10 W fluorescent lamps should be used for most lighting needs, because they are commonly available. However, sometimes an 8 W lamp might not be the best solution. For guidance, the table below gives examples of lighting solutions for various needs.

Room	Surface area (m^2)	D* (m)	Examples of solutions
Dining room	12	1.8	1 x 11 W fluorescent lamp
Living room	12	1.8	1 x 8 W fluorescent lamp
Bedroom	10	1.8	1 x 8 W fluorescent lamp
Kitchen	8	1	1 x 8 W fluorescent lamp
Bathroom	2	1	1 x 8 W fluorescent lamp
Toilet	2	2	1 x 3 W incandescent lamp (or 1- 3 W LED lamp)
Office (environment)	10	1.8	1 x 8 W fluorescent lamp
Desk – work table	2	0.7	1 8 W fluorescent lamp with reflectors or 1 x halogen spotlight 10 or 20 W
Reading corner	1	1.8	1 8 W fluorescent lamp with reflectors or 1 halogen spotlight 10 - 20 W or 1 LED lamp (1 W to 3 W)
External lighting	-	-	1 x 8 W fluorescent lamp

*D is the maximum distance between the lamp and the surface to be lit. It is necessary that the walls and ceiling are painted white or another light colour so as to reflect the light.

Note: the levels of illumination obtained in the examples above are low by comparison with the levels of illumination in industrialized countries; but they are much higher than those obtained with oil lamps or candles.

Read with the trainees the table on **page 35 of the Paper Tool.**

Show fluorescent lights, LED lamps and any other lamps available.

4.1.4 Choosing other appliances (TV, refrigerators)

Refer to the information on **pages 36 and 37 of the Paper Tool**.

4.2 Inverters

An inverter is an apparatus capable of transforming direct current (DC) into alternating current (AC).

Before going through the table on page 38 of the Paper Tool, make a table that list the advantages and limits of an inverter.

4.2.1 Advantages

- Inverters permit the use of AC appliances with a DC power supply, 12, 24 or 48 V.
- Cable sizes are reduced as the current drawn in CA 230 V systems is smaller than the current drawn in 12 or 24 V DC systems for the same distributed power.

Ave trainees compare the current drawn by a 100 W – 12 V DC TV with a 100 W – 230 V AC TV (with a power factor equal to 1).

4.2.2 Limitations

- Inverters consume energy as they are not 100% efficient (usually between 50 and 80%), which in turn increases the size of the PV system panel and battery.
- They have a stand-by electrical consumption (from 1 to 20 W). They consume energy as long as they are plugged in even if they do not supply energy.
- If they are directly connected to a battery (without the overcharge protection of the regulator), the battery is not protected against deep discharge. Inverters have their own low voltage protection, but it is very low about 10.5 V.
- Inverters are extremely difficult to repair, especially newer generation models which have solid state electronic components.
- The output signal depends on the quality of the inverter (this can be from a basic square signal to "quasi sine wave" signal).
- Inverters add to the complexity of a system (sizing, installing and maintenance).
- Usually quite expensive.

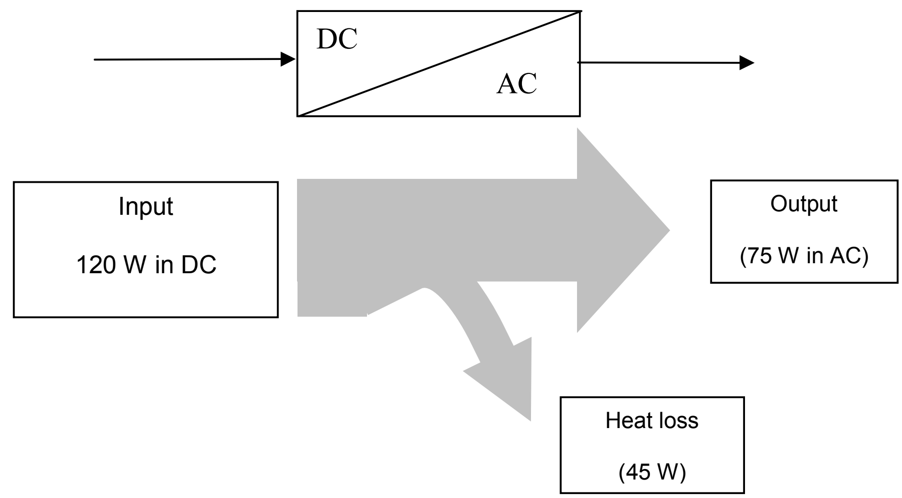
4.2.3 Inverter efficiency

As seen in Module 2, the formula for Efficiency is:

$$Efficiency = \frac{Output}{Input}$$

In the case of an inverter:

The Input is the DC power (coming from the battery)
The Output is the AC power (consumed by the AC load)



Efficiency = 75 W /120 W = 62.5%

4.2.4 Signal output

The cheapest and most basic inverters produce a square wave AC output. They are relatively inefficient (only 50 to 60%), even at rated power, and often highly inefficient at part load. These inverters are easily recognizable as they are bulky and very heavy.

More sophisticated inverters are more expensive, but produce a 'quasi-sine wave' output (i.e. approximately equivalent to normal mains AC power). They are also more energy efficient at rated power (the best are around 90% efficient) and much more efficient at part loads.

4.2.5 Automatic load detection

The very best inverters are equipped with automatic load detection. They are designed to switch themselves off at no-load to reduce the consumption of energy (less than 0.5 W) when no receiver is connected.

The danger with inverters that do not have this feature is that they can drain the batteries to which they are connected, due to their own parasitic power demand (between 5 to 10 W) even when no power is being drawn.

The automatic load detection must be able to detect resistive loads (e.g. incandescent lamps) as well as inductive loads (such as certain fluorescent luminaries). This detection level, from which the inverter feeds a load, can be adjustable on certain models of inverters.

If the inverter does not have a system of automatic load detection (most small inverters do not have this), it is imperative to place a switch on the input circuit of the inverter, to completely isolate the inverter from the battery. This avoids consuming energy unnecessarily, when no load is connected.

4.2.6 Inverter sizing

The nominal power of an inverter (VA) is the maximum power that can be delivered in continuous running, with adequate output voltage and with an ambient temperature between 0°C and 40°C.

Power is expressed as VA, rather than as W to take into account the power factor of the appliances as explained below:

Example: a 200 W -230 V AC electric motor with a power factor of 0.7

$P = U \times I \times \cos\varphi$[1] $= V \times A \times \cos\varphi \rightarrow VA = P / \cos\varphi \rightarrow VA = 200 / 0.7 = 285$ VA. The inverter will need to have a power rating of at least 300 VA. This unit will supply an output current of 1.24 A (e.g. 285 VA / 230 V).

Example: a 200 W - 230 V AC electric motor with a power factor equal to 1

$P = U \times I \times \cos\varphi = V \times A \times \cos\varphi \rightarrow VA = P / \cos\varphi \rightarrow VA = 200 / 1 = 200$ VA.
The inverter will need to have a smaller power rating: 200 VA. This unit will supply an output current of 0.87 A (e.g. 200 VA / 230 V).

Conclusion: it is best to choose loads with a power factor close to 1, because the inverter power rating can then be smaller.

Since many electrical appliances (especially devices with electric motors, such as power tools or refrigerators) draw a surge of current greater than their normal power requirement when switched on, some overload capacity is generally an important requirement. Otherwise, there is a risk of burning out either the inverter or the appliance.

Another important feature with inverters is their overload capacity. It is best if the inverter can support 250% over charge during 15 seconds and also 125% during 60 seconds. In this case, it should be able to start small electrical engines.

Rule:

An inverter must have a nominal output (validated under continuous operation) approximately 2 to 3 times higher than the total power of the loads to feed. This will enable it to absorb the various values of power-factor, as well as the peaks of inrush currents of certain apparatuses (for example, certain television sets or electric motors).

Have trainees measure the efficiency of an inverter through a practical exercise. Use 2 multimeters on the DC side and 2 multimeters on the AC side, a 200 W inverter powering a 35 W TV and a 20 W VCR.

Draw conclusions about the efficiency of the inverter, mention the necessity to use multimeters set to AC measures for the AC side of the inverter.

[1] Refer to Module 2, relationship between U and I in AC.

4.2.7 Electrical protection

1. **DC side:** the system must be protected by a fuse (or circuit breaker) at least on the positive cable close the battery. Protection against the inversion of polarity is always recommended.

2. **AC side:** the inverter (and the distribution system) must be protected from short-circuits or overloads, by means of external circuit breakers. A single protection by fuse is not recommended.

   Important note: in the event of a short-circuit on the exit AC, the external circuit breakers or fuses will often react too late and the inverter will be `roasted' (except it has its own internal protection against short-circuit).
   The transformer and the elements of commutation of the inverter must be protected internally from over-current, overheating and short-circuit. These safety devices must be reinitialized automatically or manually once the defect is removed.

Note for solar systems

It is necessary to respect local or national regulations for electric installations of 230 V AC as well as the technical information supplied with the inverter as far as electrical safety is concerned.

For example, the output of the inverter should be equipped with a differential circuit breaker. (30 mA) . In general, connect the Neutral from the inverter to the earth bar and, the metallic mass of the loads and inverter should be connected to the earth wire as well. It is also necessary to place differential circuit breakers at the inverter output. .

4.3 DC-DC adapters and converters

Adapters (also called: *power conditioner*) are required to step down voltage for appliances lower than 12 V DC (e.g. 12 V DC phone charger). They are made of relatively simple electronic components.

The adapter should be selected so that its power output is always higher than the appliances connected to it.

Cheaper adapters are of very low quality (i.e. they will not last long) and have a low efficiency.

More expensive adapters are more reliable and usually have an internal fuse.

Ask the trainees to choose the setting of a DC-DC adapter in the following cases: for a radio with 2 dry-cells, for a radio with 4 dry-cells, 6 dry-cells, 8 dry-cells, and 10 dry-cells.

The answers are:
for 2 dry-cells : 3 V,
for 4 dry-cells : 6 V,
for 6 dry-cells : 6 V,
for 8 dry-cells : no need for a DC-DC adapter !
for 10 dry-cells: no need for a DC-DC adapter !
10 cells make 15V, but most 10 cell radios work well on 12 V DC from a battery

Have trainees connect a DC-DC adapter to a 12 V battery to power a 4 or 6 V radio. Ask them to measure the current and voltage before and after the DC-DC adapter. They should be using 4 multimeters.

Ask them to calculate the power on the 12 V side and the power on the 4 or 6 V side. Help them to draw conclusions regarding the efficiency of the DC-DC adapter.

Converters

A converter is a device that can step up the DC voltage (i.e. from 12 V DC to 24 V DC). Converters generally have a more complicated design and are not readily available everywhere. Their efficiency is often greater than an adapter.

4.4 Choice of cables and voltage drops

(Refer to **page 40 of the Paper Tool**)

4.4.1 Cables and voltage drops

Cables are necessary to connect all the major components of a PV system at an adequate voltage. For instance, a 12 V DC lamp needs to be fed with a voltage very close to 12 V, not 10.5 V. Such a low voltage would damage the lamp and reduce its lifetime!

Any cable that connects a lamp to a system will create a voltage drop: the voltage that arrives at a load will be less than the voltage from the source (the battery).

The amount of the voltage drop depends on:

- the **length of the cable** (in meters),
- the section (width) of the cable (this relates to its electrical resistance **R in Ohm** / meter of cable) and
- the amount of current **I in Amp** travelling in the cable.

Voltage drop = Cable length x R x I

wire section (mm^2)	1	1.5	**2.5**	4	6	10	16
Cable Resistance (Ohm / meter) R	0.040	0.0274	**0.01642**	0.01018	0.00678	0.0039	0.00248

Important: a cable is composed of two main wires. This table is valid for the length of cable, not the total length of wire.

For example, when a 13 W / 12 V lamp (I = 13 W / 12 V= 1.08 A) is connected to a 12 V battery using 30 m of thin cable (i.e. 1 mm^2), similar to a loudspeaker cable, the voltage drop will be:

$$V\ drop = 30\ m \times 0.040\ ohm/m \times 1.08\ A = 1.29\ V$$

This means that if the battery is at 12 V, the lamp will receive only 12 V – 1.29 V = 10.71 V! This can be quite bad for the lamp. It will not light very well, the tube will blacken quickly and eventually the lamp will not even light at all and be spoiled.

Have the trainees to calculate the voltage drop if the cable is bigger, i.e. 2.5 mm^2, and 4 mm^2.

The answers are:
For 2.5 mm^2, V drop = 30 x 0.01642 x 1.08 = 0.53 V, the voltage drop is much smaller.
For 4 mm^2, V drop = 30 x 0.01018 x 1.08 = 0.33 V, the voltage drop is even smaller.

Conclusion, the thicker the cable, the smaller the voltage drop.

Ask the trainees to calculate the voltage drop if the cable length is twice less or half.

Draw the conclusion: the shorter the cable, the smaller the voltage drop.

Ask the trainees to calculate the voltage drop if the lamp is only an 8 W lamp (I = 8 W / 12 V = 0.66 A).

Draw the conclusion: the smaller the current, the smaller the voltage drop.

It is crucial that in addition to the theoretical calculations **(Voltage drop = Cable length x R x I),** the trainees be able to measure a voltage drop that they can compare with their calculations (i.e. the theory).

Ask the trainees to take 10 meters of 2.5 mm2 cable and connect a 13 W lamp at one end and a battery at the other end (do not forget to insert a fuse).

Have the trainees measure the current consumed by the lamp with one multimeter in series and the voltage drop with another multimeter, (i.e. the voltage at the battery minus the voltage at the lamp). (They can also measure the voltage drop at every meter of cable).

Then ask them to calculate this voltage drop.

The answer is:
I consumed by the lamp is: I = P / U = 13 W / 12 V = 1.08 A. V drop = 10 x 0.01642 x 1.08 = 0.17 V. The measurements with the multimeter should give similar results. Perform this exercise again until the trainees understand clearly what a voltage drop is and how it is calculated.

4.4.2 Voltage drops represent power losses

Ask trainees - What is the formula to calculate electrical power? Then ask the trainees what is the power wasted by a cable when a voltage drop is high (1.2 V) and the current 1.00 A.

The answer is:
P = U x I. In this case: P cable = 1.2 V x 1.00 A = 1.2 W! This power is wasted power that will have to be produced by the solar panel! This is another reason to reduce voltage drops whenever possible.

4.4.3 Maximum admissible voltage drops in a small 12 VDC PV system

As seen above, voltage drops are detrimental to a solar system installation (i.e. power losses and risk of damage to equipment when the voltage is too low). For these reasons, cables should be sized to avoid voltage drops greater than those listed below:

Between the PV module and the regulator	**0.3 V Maximum**
Between the regulator and the battery	**0.15 V Maximum**
Between the regulator and lamps and other loads	**0.3 V Maximum**

Note: be aware that in addition to the voltage drop in cables, there are other very small voltage drops within the regulator (refer to **Module 6, Regulator**).

4.4.4 Choosing the nominal voltage of a solar system

For a given electric output, the lower the voltage is, the higher the current. Consequently, the currents are stronger in a 12 V system than in a 230 V system.

Example: In the case of two 8 W incandescent lamps, one functioning in 12 V and the other 8 W lamp functioning in 230V,

$$P = U \times I \rightarrow 8\text{ W} = 12\text{ V} \times \mathbf{0.66}\text{ A} = 230\text{ V} \times \mathbf{0.035}\text{ A}$$

For the same power, the intensity in 12 V is 18 times greater than the intensity consumed under 230 V.

Have the trainees calculate the current drawn by a 70 W TV, when it is a 12 V DC TV, a 24 V DC TV and when it is 220 AC TV.

The answers are:

If the TV is 12 V DC, I = P / U = 70 W / 12 V = 5.83 A.
If the TV is 24 V DC, I = P / U = 70 W / 24 V = 2.91 A.
If the TV is 220 V AC, I = P / U = 70 W / 220 V = 0.32 A.

The current is 18 times smaller in AC current than for the 12 V DC. The calculation of the current drawn in AC is approximate here. The right formula to use should be: P = U x I x 0. 7 for a TV in AC power (0.7 is the Power Factor). This gives a slightly higher current: 0.45 A (instead of 0.32 A).

In the case of small PV systems (less than 250 Wp), the system voltage is commonly 12 V.

If the system exceeds 250 Wp, it may be the preferable to use a 24 V DC solar generator for distribution in 230 V AC. In the case of a 24 V system, weaker section cables may be used, but it will be necessary to install a regulator and a 24 V battery and all the loads must be able to function in 24 V. The latter are not as widespread as 12 V DC loads.

Between 250 Wp and 1000 Wp, it is often best to install an inverter to power all loads. The solar generator (panel, regulator, battery) is then wired in 24 V DC (more rarely in 12 V DC).

For systems above 1000 Wp, the solar generator will be wired in 48 V DC and the distribution in 230 V via an inverter 48 V DC / 230 V CA.

Typical voltage/configuration

System size	Solar generator voltage (panel/regulator/battery)	Load nominal voltage
0 to 250 Wp	12 V DC	12 V DC
250 to 1000 Wp	24 V DC	24 V DC or 230 V AC
Above 1000 Wp	48 V DC	230 V AC

Caution: this table indicates typical configurations. Dimensioning must be done on a case-by-case basis.

4.5 Electrical and lightning protection

4.5.1 Fuses and circuit-breakers

In order to protect the installation and the users against short-circuits, it is essential to install electrical protections. The simplest and most common protection is the **fuse.**

1. A fuse should be fitted between the **regulator** and the **battery.**

2. A fuse should be fitted between the **regulator** and the **loads (on the positive terminal).**

In some cases, charge regulators are already fitted with fuses, especially on the load side. In this case, there is no point in adding extra fuses on the load side. **Fuses in a circuit create voltage drops**, this is one good reason to avoid adding extra fuses.

Circuit breakers are installed instead of fuses. They are more expensive, but require no spare parts (no replacement of fuse cartridge).

4.5.2 Fuse rating (in Amp)

The fuse rating should be greater than the maximum current passing through the circuits and appliances (refer to **Module 9** for a detailed example of fuse sizing).

Rules:

1- **Select a fuse rating that can accept 1.25 to 1.5 more current than the nominal current of the loads.**
2- **Never replace a fuse with a piece of copper wire.**
3- **Always replace a blown fuse by a fuse of the same rating.**
4- **Check regularly the voltage drop of the fuses.**

Ask trainees to choose the rating of a fuse to be placed between the regulator and the loads if the 12 V PV system has 6 x 13 W lamps and a 10 W radio cassette player.

Answer: Total power is : 6 x 13 W + 1 x 10 W = 88 W. The maximum current drawn will be:
I = P / U = 88 / 12 = 7.33 A. The fuse rating should then be 1.25 x 7.33 A = 9.16 A, i.e. 10 to 15 A.

Do the same exercise, but with a 24 V PV system.

Answer: Total power is : 6 x 13 W + 1 x 10 W = 88 W. The maximum current drawn will be:
I = P / U = 88 / 24 = 3.66 A. The fuse rating should then be 1.25 x 3.66 = 4.57, i.e. 5 A.

4.5.3 Lightning protection

Solar systems are vulnerable to the induced effects of lightning and of course to direct lightning strikes.

Direct lightning strike: No system can resist a direct lightning strike. In such cases, the system is generally destroyed: PV modules may be broken, the regulator may be blown, the battery exploded, etc. These cases are rare however.

Induced effects of lightning: These are mainly the effects of overvoltage that can destroy electronic components, especially low voltage ones.

Protection techniques

In the areas where lightning storms are frequent, the following issues must be taken into consideration to minimize the risks related to the induced effects of lightning.

Choice of equipment / installation techniques

1. Install the modules as low as possible, while avoiding shading.

2. Choose the regulator and inverter with built-in over-voltage protection devices (usually they are made of zinc-oxide varistors).

3. Ground the module and its structure. Connect a wire with a cross-section of at least 10 mm^2 (16 mm^2 is preferable) to the aluminium frame of the module and then bury the other end connected to an adequate earth rod (at least 1.5 meters deep).

User implications / user training

4. Alternatively (or as additional measurement of protection), install a bipolar switch between the module and the regulator. When lightning is forecast, the user should turn off the switch. As a consequence, the installation is protected from lightning surges coming from the modules. However, it is very important to train the user to turn on the bipolar switch when the lightning storm is over to allow the panel to recharge the battery. This solution is very effective provided that the user is trained when and how to turn off and on the switch.

5. Advise the user to disconnect all the loads (connected to sockets) during lightning storms. If there is a TV antenna, this must also be disconnected from the TV.

6. As an additional measure, disconnect the output of the inverter during lightning storms.

The protection of systems against lightning induced effects is not often simple to manage. Before installing any protection techniques (or deciding not to install one), it is recommended to consult the manufacturer/or supplier of the material who may have experience with the equipment and in the area the system is to be installed.

4.6 Quality control when purchasing loads, inverters and cables

The following advice should be kept in mind when purchasing equipment.

- Always check the labelling on appliances (e.g. Voltage inputs, Power consumption, etc.). Usually poor labelling means that equipment is of dubious quality.
- Always ask for technical documentation. If no documentation exists, this may also be a sign that the equipment is of poor quality.
- Do not hesitate to double check power consumption whenever necessary. Unfortunately, the information given is not always accurate. Some lamps equipped with an 8 W fluorescent tube may consume up to 15 W! Watch out for these.
- Fuses: Choose fuses with low voltage drops and good corrosion resistance, in particular if the fuse must be installed in a battery box.
- Inverters: ask the supplier/salesman, to demonstrate the correct operation of the inverter (with various types of loads). Check that the inverter has an internal protection against short-circuit on the AC side.

  Small inverters are relatively new devices on the consumer market and until recently they had a tendency to be unreliable. It is certainly worth trying to find an inverter that has a proven 'track record' and is widely used, as well as having good efficiency across its power spectrum from 'no load' to 'maximum rated power'.

- Cables: Check the section of the cables at the supplier's shop. Certain cables sold with a label specifying 2 x 2.5 mm^2 are in fact cables 2 x 1 mm^2! If the cables must be installed outside, choose cables resistant to ultraviolet rays or to envisage sheaths resistant to UV. Always try to purchase **cables where the dimension is CLEARLY PRINTED on the outside of the cable, e.g. 2 x 2.5 mm^2.**
- Always try to obtain the most interesting possible guarantees with equipment purchases.
- Always check the availability of spare parts to facilitate maintenance and breakdown services.

5 Assessment and Feedback

This section is for the Trainers to ensure that Trainees have understood the main concepts presented in this module. The concepts taught here are fundamental for proceeding to the following modules. As such, the trainer needs to assess how well trainees have understood the concepts taught here. This can be done in several ways.

Suggested activities to be carried out in teams, individually or as an individual session:

- List the most suitable loads for a small solar system (type of lamps, etc.).
- Enumerate the 3 parameters influencing voltage drops in cables.
- Calculate the voltage drop over a 20 m cable with a section of 2.5 mm^2 carrying a current of 2.5 A, 5 A and 10 A. The electric resistance of the cable is 0.01642 ohm / metre.
- State the maximum authorised voltage drop between the PV module and the regulator, between the regulator and battery and finally between the regulator and loads/appliances.
- Choose the fuse gauge necessary to protect an installation where the loads are 250 W under 12 V DC.
- Indicate where fuses should be installed to protect the installation from short-circuits.
- Describe 2 ways of protecting an installation from lightning strikes.
- Explain why inverters should be avoided in the case of a small solar system (advantages and disadvantages of an inverter).
- Explain why an inverter should have its own internal short-circuit protection.
- Make a list of the quality control parameters when purchasing lamps, cables, DC-DC adapters and finally inverters.

Important note : if the training course is to result in the qualification of trainees for a certain level, it is suggested to give similar exercises as those that will be given on the examination day.

This has the advantage of preparing the trainees for the final qualification examination and evaluation[2].

[2] Examinations should always be conceived for success, and not to lead to failure.

MODULE 9 : Sizing and Price quotations

1. Objectives

The learning objectives of this module are;

- How to size small PV system components;
  - PV module,
  - battery,
  - regulator,
  - fuses, and
  - cables.

- How to make a price quotation for a complete PV system.

This module details the sizing of the modules, battery and regulator of the case study given as an example in Annex 2 of the Paper Tool.

2. Module duration

8 – 12 hours

3. Necessary teaching equipment

Description	**Qty (minimum)**
Sizing procedure form (found in the Paper Tool)	3 per trainee
Quotation procedure form (found in the Paper Tool)	3 per trainee
Solar calculator (one per student)	1 per trainee
Price list of solar equipment from local supplier	1
Set of manufacturer technical documentation for modules, regulator and battery.	1

4. Content

4.1. Introduction

The size of a solar system affects the price, quality and durability of an installation. Hence sizing is a crucial step.

The procedure for sizing a small PV system is rather simple, although the detailed sizing of a large PV system can become quite complex.

In general, sizing methods are easy to use but have their limitations. The results of a sizing method cannot be assumed to be 100% because of the following factors; solar energy input data (the Irradiation), the assumptions about the energy requirements of the client, and equipment data are not always reliable.

The solar Irradiation varies from year to year (ranging from plus to minus 10%). The client's electricity consumption is likely to fluctuate. Therefore, even when the size of a system is calculated carefully, shortages of electricity may occur from time to time, as well as periods of abundance. In the latter case, clients will never complain!

4.1.1. Simplified sizing procedure form

- This module explains a basic sizing method, accurate enough for small PV systems.
- The proposed method allows for the sizing of a PV system on one single calculation form (however a separate sheet will be necessary to size the cable cross section).
- This sizing form is provided **Annexe 3** of the **Paper Tool**.

4.1.2. The 5 steps for sizing

Ask the trainees to recall the steps that were presented in Module 4 (refer to page 20 of the Paper Tool).

4.2. Evaluation of the client's energy needs

The evaluation of the client's energy needs was detailed and explained in **Module 4**.

4.2.1. Energy needs of the client (Nd)

Ask the trainees to make a table like the one in Annexe 3 (or use a copy of this procedure form).

Then use the data in Annex 2 to calculate the energy needs.

On the sizing procedure form (Annex 2 or 3) :

* Nominal Power is the power rating (i.e. power consumption) of an appliance. Usually, the power and the voltage are labelled on appliances. If it is not written, then it must be calculated by connecting the appliance to a power supply (e.g. a battery) and measuring current and voltage. Then use the formula P = I x U. If the appliance is an AC appliance, use the formula: P = I x U x Power factor.

4.2.2. Explanation: in case of the use of an inverter

If the appliances function in AC current, then an inverter is necessary.

Inverter efficiency and AC power known:

If the inverter efficiency is known to be 70%, and the appliance is 50 W, then in reality it will consume 50 / 0.7 = 71.4 W. If the appliance is used for 4 hours per day, the energy consumed is 71.4 W x 4 hours = 286 Wh.

Inverter efficiency and appliance power unknown:

In the case of AC appliances, it may be difficult to estimate the energy needed from the battery as the efficiency of the inverter is not always known, or precise, nor is the power consumed by the appliances. It is possible to estimate these values with experience, or you may proceed using the following method (if the appliances are available).

1. Plug in the AC appliance(s) to the inverter.
2. Measure the intensity of the DC current and the DC voltage coming into the inverter.
3. Calculate the power consumed in DC.
4. Check the coherence of your result; the DC power input should be greater than the AC power coming out of the inverter.
5. Use this power value and multiply it by the duration of use in hours of the appliance in order to estimate the energy consumption (Wh / day). Record this value in the table in section 4.2.1.

Example

If a TV is connected to an inverter and the DC current is measured to be 5.85 A in 12 V, then the power consumed by the TV is P = 5.95 A x 12 V = 71.4 W. The appliance consumes about 50 W in AC (see label on the appliance), but the inverter consumes 71.4 W for the entire duration of use (e.g. 5 hours).

Energy consumed by the TV: 50 W x 4 h = 200 Wh
Energy consumed by the inverter to power the TV : Nd = 71.4 W x 4 h = 286 Wh

The solar system (the PV modules) must produce 286 Wh / day, and not only 200 Wh!

4.3. Solar array sizing

A single PV module may be referred to as a module. A group of modules linked together is known as an array. The size of a PV module or array should be able to:

1. Produce sufficient energy to meet the client's daily needs (the client's loads).

2. Produce energy to compensate for energy losses in the battery (i.e. battery charging and discharging efficiency – refer to **Module 7**). The **battery charge/discharge efficiency rate (EB)** characterises these energy losses.

3. Produce energy to compensate for various other energy losses in the installation (i.e. losses in cables due to voltage drops, the regulator, etc.). The **installation energy efficiency (EI)** characterises these losses.

Consequently, the size of the module or array (in Pp) can be calculated as below:

Peak power (Pp) = (Nd in Wh) / (EB x EI x IRR) (in Wp)

where:

Nd : Daily energy needs

EB : battery charge/discharge efficiency rate, usually estimated at 70%

EI : installation efficiency, usually estimated at 85%

IRR : mean daily irradiation of the worst month (e.g. 4.5 kWh/m^2/day).

Nd = Real Need (Wh)		EB		EI		IRR		Peak power (Wp)	**Qty of modules (Nm)**
532	/	0.7	/	0.85	/	4.5	=	***198.6***	

It is necessary to choose PV panel(s) with a peak power rating higher than 198.6 Wp. The right choice will depend on the type, availability and prices of locally available modules (e.g. 4 x 50 Wp modules or 3 x 75 Wp modules)

Ask the trainees to size a PV panel or array for the following energy needs: 12 Wh, 150 Wh, 1200 Wh.

The answers are:

12 Wh	*: panel(s) should be at least:*	*4.48 Wp →*	*1 module of 5 Wp*
150 Wh	*: panel(s) should be at least:*	*56 Wp →*	*1 module of 60 Wp*
1200 Wh	*: panel(s) should be at least:*	*448 Wp →*	*9 modules of 50 Wp*

4.4. Battery sizing

The capacity of the battery should be:

1. Large enough to supply the daily electric energy requirements of the loads (This energy is provided by the module during each day). This is the **Usable Capacity.**

2. Large enough to supply the daily energy requirements at night, even if there has been cloudy / rainy weather for several days. For small lighting systems, it is good practice to allow for 3 days of bad weather. This number of days is known as the **Autonomy.**

3. Large enough to ensure daily shallow cycles (**small DDOD**). This implies the choice of a value of **maximum DOD.** This will ensure a long battery life.

For all these reasons, the battery nominal capacity can be calculated using the formula below:

Battery nominal capacity = (Nd x AUT) / (DOD x U) (in Ah)

Where:

AUT: autonomy in days: 1 to 5 depending on required system autonomy without sunshine, 3 days may be taken for small lighting systems. 5 days are usually recommended for solar vaccine refrigerators. AUT can be up to 8 days in countries where long periods of no sunshine are frequent.

U: System voltage (12 V most of the time). **The voltage is here to convert the Wh into Ah.**

DOD: Authorized depth of discharge. It is usually estimated as 50% (30% is better for a car battery).

Nd = Need (Wh)		AUT		DOD		U (V)		Minimum capacity (Ah)	**Chosen battery (Ah)**
532	X	*3*	/	*0.5*	/	*12.0*	=	*265.9*	*270*

Rule :
The estimated average current drawn by the all the loads must be smaller than the discharge current I_n of the chosen capacity C_n.

In general, it is safe to choose a capacity in 10 hours (C_{10}). Ex : 270 Ah C_{10}

Note: If the client is willing to buy a solar battery, it is possible to choose a higher DOD. For example, if one chooses a DOD of 70%, the minimum capacity of the battery will be:
(532 x 3) / 0.7 / 12 = 190 Ah. The battery capacity is smaller, but that does not mean that it will be cheaper. Remember, dedicated solar batteries are more expensive per unit of Ah.

SIZING RATIO FOR DOUBLE-CHECKING: it is important to calculate the DDOD, as this will give an excellent indication of the likely lifetime of the battery.

Ask the trainees to remember what is the DDOD (Daily depth of discharge) and ask them to calculate it.
Answer: (532 Wh / 12 V) / 270 Ah = 0.164 = 16.4 %:

4.5. Choosing the regulator

4.5.1. Standard case

Choosing a regulator has been fully explained in **Module 6.** The regulator must be able to withstand at least:

1. the maximum short circuit current produced by the panel and
2. the maximum current drawn by the loads when **they are all switched ON.**

Sizing rule :

The regulator must have :

- Maximum current accepted from the PV panel	> **(+ 25 %)**	**Maximum short–circuit current of the PV panel (Isc)**
- Maximum current deliverable to the loads	> **(+ 50 %)**	**Sum of the current drawn by the loads**

The following is the continuation of the case study.

At this stage, ask the trainees to fill in Section 4 of Annex 3.

The panel Isc is 12.2 A (use the data sheet from the manufacturer: e.g. 4 x 50 W modules, with each module an Isc = 3.05 A).

The sum of the load current is equal to 12.17 A (see the Table in Annex 2 of the Paper Tool or the table that has been filled by the trainees)

The regulator will need to have:

- **Maximum current accepted from the PV panel** > 12.2 A x (1 + 25 %) = 12.2 x 1.25 = 15.25 A
- **Maximum current deliverable to the loads** > 12.17 x (1 + 50 %) = 12.17 x 1.50 = 18.25 A.

A 20 A – 20 A regulator will be necessary.

Ask the trainees to check if there is a regulator that is suitable among those available at the training venue by reading their available technical documentation.

4.5.2. System with an inverter connected directly to the battery

The regulator is not crossed by the current drawn by the AC loads, because the inverter is connected directly to the battery. In this case, the regulator needs only to withstand the Isc current from the PV array.

Beware that in such a case, the batteries are not protected against deep discharge. Their lifetime will be shortened unless the inverter is manually switched off when the battery voltage becomes too low.

4.6. Fuses

Rule

The fuse rating (nominal current) must be greater than the maximum current that will flow in the cable to be protected (+ 50 %).

4.6.1. Standard case

The fuse (**between battery and regulator**) will have the charge current from the panel flow through it (I maximum = Isc) and it will also have the current consumed by the loads flow through it (the sum of loads currents, including loads powered by an inverter).

The size of the fuse must be greater than the larger of these two current values.

Maximum current between battery and panel (I_{panel}):

With a 200 Wp PV panel, the current Isc is 12.2 A. Consequently, the maximum current between the panel and the battery will be: I_{panel} = 12.2 A.

Maximum current consumed by the loads (I_{loads}):

The maximum current consumed by the loads is I_{loads} = 12.17 A.

$$I_{panel} > I_{loads}$$
$$12.2\ A > 12.17\ A$$

In this case, one should choose a fuse size of: 12.2 x (1 + 50 %) = 12.2 x 1.5 = 18.3 A, or a 20 A fuse.

Case where a fuse is placed between the regulator and the loads

It may be necessary to place fuses between the regulator and the loads for systems above 250 Wp. Be careful to avoid voltage drops however.

4.6.2. Case of an inverter connected directly to the battery

Fuse on the DC side

An inverter is connected directly to the battery and not on the regulator at the *Loads* output. **Unless the inverter is already equipped with a fuse on its DC input**, it is necessary to place a fuse between the battery and the inverter input. It should be capable of withstanding the maximum current and start up currents.

Example: An inverter has a output power of 300 VA. The maximum input DC current will be: I = P / (inverter efficiency rate x 12 V) = 300 / (0.7 x 12 V) = 35 A. The fuse should be 35 A x 1.5 = 52.5 A. It can be bigger in cases where surge currents or starting currents are greater than those calculated here.

Fuse on the AC side

It is preferable to connect a fuse on a 230 V system at the inverter AC output level. It will be much smaller than that connected at the inverter input level as the voltage is greater (230 V AC).

4.7. Cable sizing with a practical example

Rule: Voltage drops are calculated along each circuit by taking the **maximum** current crossing each part of the circuit. Voltage drops must be less than the values indicated in the table below.

Between PV module and regulator	**0.3 V Maximum**
Between regulator and battery	**0.15 V Maximum**
Between regulator and lamps or other loads	**0.3 V Maximum**

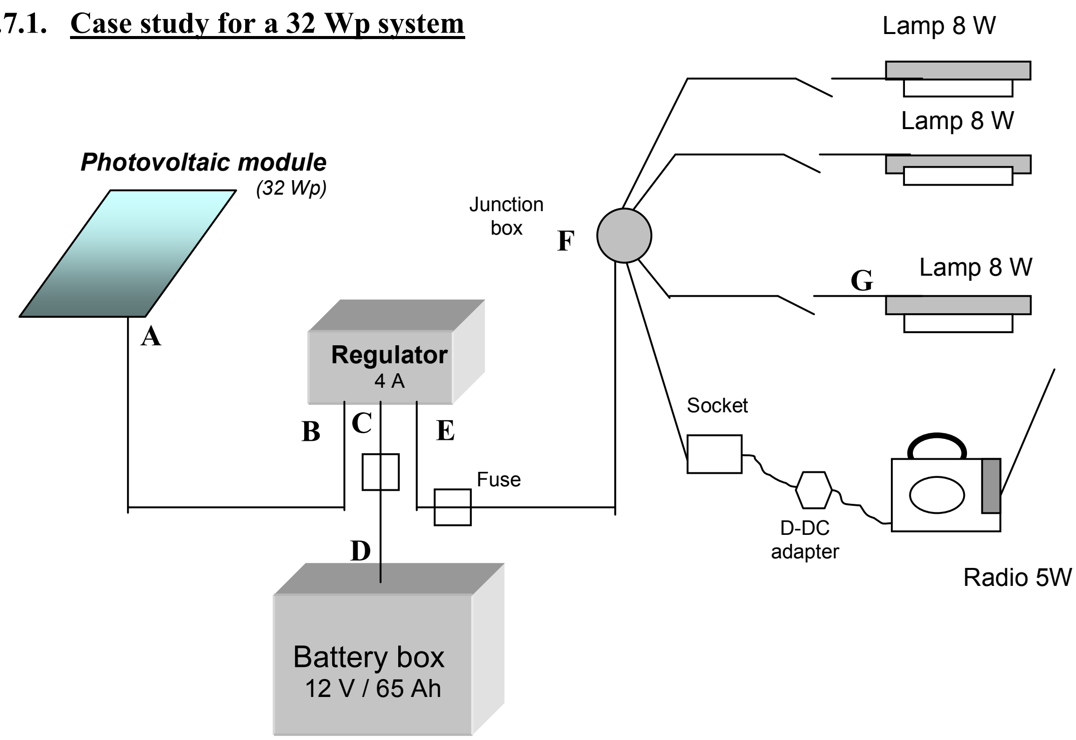
Each voltage drop is calculated with the formula and values for cable resistance as shown below:

Voltage drop = ΔU = cable length x R x I

Cable section (mm2)	1	1.5	**2.5**	4	6	10	16
Cable resistance (Ohm / meter R	0.040	0.0274	**0.01642**	0.01018	0.00678	0.0039	0.00248

This is valid for a two core cable: e.g. 2 x 2.5 mm².

4.7.1. Case study for a 32 Wp system



Installation details

Section	Distance (m)	**I max (A)**
Section **A-B**	7	**1.9**
Section **C-D**	1.5	**2.42**
Section **E-F**	3	**2.42**
Section **F-G**	10	**0.66**

__Step 1__: **calculate the maximum current crossing each part of the circuit** and write these values in a table (Imax), but also on the electric circuit.

__Step 2__: Cable between the PV Panel and the Regulator

The cable section (size) is 2.5 mm^2 and the distance (A-B) between the module and the regulator is 7 meters. Maximum current is the Isc of the 32 Wp PV module (1.9 A).

Voltage drop = ΔU_{AB} = cable length x R x I = 7 x 0.01642 x 1.9 = 0.21 V

This is acceptable because it is below 0.3 V.

__Step 3:__ Cable between the Regulator and the Battery

The cable section is 2.5 mm^2 and the distance (C-D) between the regulator and the battery is 1.5 meters. The maximum current passing through the cable is 2.42 A.

Voltage drop = cable length x R x I = 1.5 x 0.01642 x 2.42 = 0.059 V
The voltage drop caused by the Fuse must be added: this is estimated at 0.05 V

Total voltage drop = ΔU_{CD} = 0.059 V + 0.05 V = 0.109 V

This is acceptable because it is below 0.15 V.

__Step 4:__ Cable between the Regulator and the Junction Box

The cable section is 2.5 mm^2 and the distance (E-F) between the regulator and the junction box is 3 meters. Maximum current is 2.42 A.

Voltage drop = cable length x R x I = 3 x 0.01642 x 2.42 = 0.12 V
The voltage drop caused by the Fuse must be added: this is estimated at 0.05 V

Total voltage drop = ΔU_{EF} = 0.12 V + 0.05 V = 0.17 V

__Step 5:__ Cable between the Junction Box and one Lamp

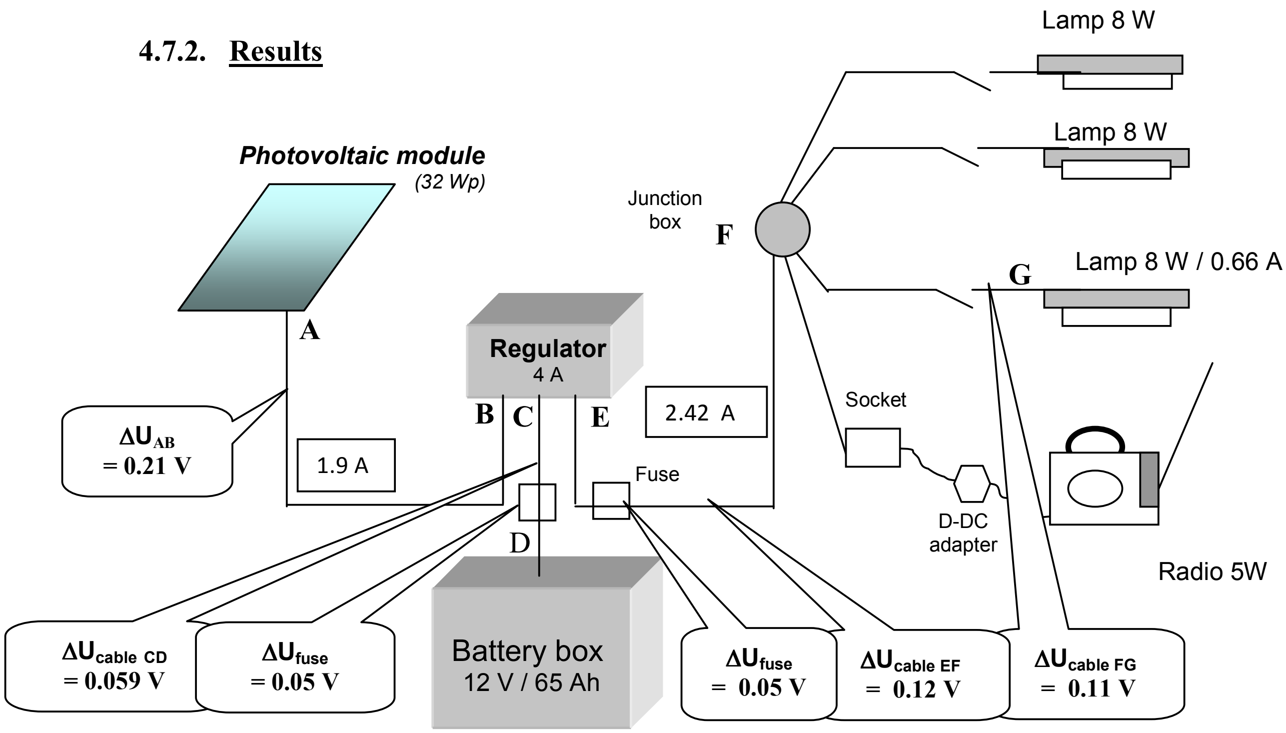
The cable section is 2.5 mm2 and the distance (F-G) between the junction box and the lamp is 10 meters. Maximum current passing through this cable is 8 W / 12 V = 0.66 A.

Voltage drop = cable length x R x I = ΔU_{FG} = 10 x 0.01642 x 0.66 = 0.11 V.

__Step 6:__ Total voltage drop between the Regulator and one Lamp

Voltage drop between E and G = ***ΔU_{EFG} = ΔU_{EF} + ΔU_{FG} = 0.17 V + 0.11 V = 0.28 V****.*
This is acceptable because it is below 0.3 V.

4.7.2. Results



For more clarity, the calculations can now be presented as a table:

Section	Section	Cable length (m)	R cable (ohm/m)	I max (A)	Voltage drop (V)
Voltage drop between module and regulator (A-B)	A-B	7	0.01642	1.9 A	**0.21 V**
				ΔU_{AB}	*0.21 V*
Voltage drop between Battery and regulator (C-D)	C-D	1.5	0.01642	2.42 A	**0.059 V**
	Fuse	-	-	2.42 A	**0.05 V**
				ΔU_{CD}	***0.109 V***
Voltage drop between regulator and lamp (E – G)	E-F	3	0.01642	2.42 A	**0.12 V**
	Fuse	-	-	2.42 A	**0.05 V**
	F-G	10	0.01642	0.66 A	**0.11 V**
				ΔU_{EFG}	***0.28 V***

Other steps: The same calculations can be made for the other lamps and the radio.

4.8. Making a price quotation for a solar system

Making a price quotation for a solar system is quite simple. One simple rule for calculating a price estimate is to avoid forgetting any items of the system.

> Ask the trainees to think of a method to price a solar system.
>
> Help them to do this by using the method described on **page 24 of the Paper Tool.**

A simplified form has been developed, the *Quotation Procedure Form,* found in **Annex 5 of the Paper Tool**. This form follows the method detailed on page 24 of the Paper Tool.

In the **Paper Tool**, there is also a typical example for demonstration purposes, using the same system described in the *sizing procedure form* (**Annex 1**). The unit prices for components are real prices from West Africa in 2005.

> Ask the trainees to price a system using actual prices from the country where the training is being conducted (using a blank quotation form copied from **Annex 5 of the Paper Tool).**

4.8.1. Examples of component retail prices and other costs

PV Module

The average price for PV modules varies between 3 to 10 € / Wp, according to the quantities ordered.

Modules with higher power ratings (greater than 40 Wp) are always better value for money than smaller modules. For example, the retail price of a 20 Wp module may be 200 € (i.e. 10 € / Wp), whereas the retail price of a 40 Wp module is around 350 € (i.e. 8.75 €/Wp). Consequently, for a system needing a 40 Wp module, it is preferable to buy one 40 Wp module rather than two 20 Wp modules.

Charge regulator

The price varies firstly according to its size: maximum charge current and maximum discharge current. Secondly and to a lesser extent, price varies according to its other technical characteristics such as; signal indicator, liquid crystal screens, fuses, watertight box and temperature compensation features, etc.

The price of regulators (between 5-25 A) varies between 5 – 10 €/ A. For example a 10 A regulator can cost between 50 and 100 €.

Inverter

The price of inverters varies firstly according to its nominal power, secondly according to the quality of its output signal and finally according to its efficiency rate. Inverter prices are of the order of 1 €/W. For example, a 200 W inverter would cost 200 €. Inverter prices are decreasing as each year passes. It is now common to be able to find inverters (pure sinusoid) for a bit less than 0.5 €/W. However be wary of inverters sold between 0.1 and 0.2 €/W; often they are of poor quality (squared output signals) and their lifespan is often short.

Batteries

Indicative prices

Battery type	Cost (€/Ah)	Comments
Automotive battery	0.3 to 0.7 €/Ah	2 to 3 year lifespan if DOD is less than 30%
Solar battery (with plane plates)	1.0 to 2.0 €/Ah	3 to 4 year lifespan if DOD is less than 50%
Solar battery (with tubular plates)	1.1 to 4.0 €/Ah	4 to 6 year lifespan if DDOD is less than 60%
Sealed solar battery	1.3 to 4.0 €/Ah	3 to 6 year lifespan if DDOD is less than 60%

Note: For the same type of battery, the cost in €/Ah decreases as battery size increases.

Installation costs

Installation costs can vary considerably from one site to another. Costs depend on the following;

- Transportation costs (distance, state of the roads, type of vehicle required; motorcycle, truck, public transport),
- Labour costs,
- Food and lodging costs at the worksite (hotel or staying with the client),
- Necessary tools (ladders, special equipment, etc.).

4.8.2. Examples of system prices

The prices given in the table below are examples of retail prices based upon experiences around the world. Prices in the country where the training course is conducted may be quite different because of higher or lower import duties and taxes, different transport costs and higher labour costs.

Prices of complete systems

System	Power (Wp)	Price (€)	Local price (local currency)
Solar Radio	1	30 to 70	(see exercise proposed below)
Solar portable lantern	4 to 10	100 – 250	
Solar domestic lighting system (20 Wp, 2 lamps)	20	200 - 450	
Solar domestic lighting system (50 Wp, 4 lamps)	50	500 - 1000	
Solar electric fence	30	500 - 1000	
Solar vaccine refrigerator	200	2000 - 5000	
Solar borehole pump	250 to 800	4000 - 8000	

Ask the trainees to draw a similar table to this one to analyse local prices (in the local currency).

5. Evaluation and feed-back

This section is for the Trainers to ensure that Trainees have understood the main concepts presented in this module.

This can be done in several ways.

Suggested activities to be carried out in teams, individually or as an individual session:

- List the five steps necessary to size a system.
- Calculate the energy needs of a client who wishes to have 5 lamps of 8 W for 3 hours per day, 1 lamp of 20 W for 2 hours per day and finally a 12 V TV (17W) for 3 hours per day.
- Draw the electric schematic diagram of the installation.
- Size the solar panel when the minimum Irradiation is 4.0 kWh/m^2/day.
- Size the battery if the DOD is 30% and the Autonomy is 3 days.
- Calculate the DDOD of this battery.
- Choose a regulator for this system.
- Choose where to place the fuses on this system (between Regulator and Battery, and between Regulator and Loads).
- Detail the procedure to avoid mistakes when sizing cables : (answer : 1 - drawing the electrical circuit, 2 - write down on it the cable length, 3 - write down the maximum current on each cable; 4 - write down the maximum voltage drop
- Choose the minimum cable sections knowing that the module will be installed 12 meters from the regulator, that the battery will be 2 meters from the regulator and that all the lamps will be installed 12 meters from the regulator. The TV will be installed 5 meters from the regulator.

(Note: this assessment may not be necessary if the exercises in previous sections have been successfully completed by the trainees.)

Important note:

Important note : if the training course is to result in the qualification of trainees for a certain level, it is suggested to give similar exercises as those that will be given on the examination day.

This has the advantage of preparing the trainees for the final qualification examination and evaluation[1].

[1] Examinations should always be conceived for success, and not to lead to failure.

MODULE 10 : Installation of solar systems

1 Objectives

The learning objectives of this module are;

- How to install a complete small PV system including:

  - PV module(s),
  - battery,
  - regulator,
  - the loads,
  - the cables, and finally
  - training users how to operate their system.

2 Module duration

10 - 15 hours

3 Necessary teaching equipment

Description	**Qty (minimum)**
A complete PV lighting kit (with DC and AC loads if possible)	1
Solar calculator (one per student)	1
Multimeters	2
A set of installation tools	1
The teaching video '*Installation of Small Solar System*'	1
And TV + VCR apparatus	1
Make use of the video at the beginning of this module and for each section of this MODULE **Conclude by viewing the whole video again**	

4 Content

4.1 Definition of a correct installation

It is a good starting point to define what we mean by a good installation. What are the standards to which we will be working?

With the trainees, make a trip to visit existing solar systems installed for private owners (solar home systems) and for public institutions (schools, clinics). If visits are not possible, show a selection of pictures of solar system installations (examples of both well installed and poorly installed systems).

Ask them to record their findings and observations regarding installation techniques. Discuss their observations.

Ask the trainees to define a correct installation; eventually come to agree on the following criteria:

4.1.1 Principal criteria for a well installed PV system

1. Installation respects the wishes of the client.
2. Installation matches the quotation - no extra costs were added.
3. Components are installed according to the sizing agreement (peak power of PV modules, battery size, appliances, etc.)
4. Installation is durable (i.e. the system is designed to last for several years as PV panels last for 10 to 30 years).
5. Installation looks neat and professional i.e. aesthetically pleasing (e.g. cables are fixed horizontally or vertically, not drooping or hanging haphazardly).
6. Safety (e.g. protection of the battery to avoid children making short-circuits or coming into contact with acid).
7. Module mounting structure is sturdy to allow for safe and easy access during cleaning.
8. Installation is self-explanatory through the presence of the 'User Notice' poster nearby.
9. System components are well identified (installation date written on main components).
10. No accidents occurred during installation (e.g. avoid falling from the roof).
11. The client has been trained to use the system.
12. Existing codes and regulations are respected.

In order to achieve this, a step by step methodology for installation is recommended and is detailed in **Page 44 of the Paper Tool**.

Phase 1	Prepare and organise your work.	**Page 44 of the Paper Tool**
Phase 2	Install all major components (module, regulator, battery) and interconnect them. Put the battery to charge.	**Pages 44 to 51 of the Paper Tool**
Phase 3	Install the appliances.	**Pages 52 to 53 of the Paper Tool**
Phase 4	Carry out the finishing touches (operational test and training the user)	**Pages 54 to 55 of the Paper Tool**

The video *Installation of Small Solar System'*, is very useful for all the sections below (from 4.2 to 4.6). If you cannot play the video, go through the book step by step from pages 44 to 55.

4.2 Preparing and organising your work

1. Role-play: Ask two trainees to play a team of solar technicians and two trainees to play the clients (husband and wife). Choose a building where a small solar system has to be installed or imagine that a system has to be installed in the classroom or surrounding rooms.

Ask the 't*echnicians*' how they will proceed with the first phase of the installation. Help them categorise what they have to do, when, how and why.

2. To further assist the trainees, use the section '*Preparation for Installation*' of the Video '**Installation of Small Solar Systems**'. The duration of this section is 4 minutes.

View the video while asking the trainees to write down in detail the steps taken by the installer.

Eventually, they should come to define the steps indicated on **page 44 of the Paper Tool.**

4.3 PV module installation

Use the section '*Solar Module Installation*' in the Video '**Installation of Small Solar Systems**'. The duration of this section is 2 minutes.

View the video while asking the trainees to write down in detail the steps taken by the installer.

The trainees should come up with the steps indicated on **pages 46 and 47 of the Paper Tool.**

4.5. Battery installation procedure

Use the section '*Battery Installation'* in the Video '**Installation of Small Solar Systems**'. The duration of this section is 3.5 minutes.

View the video (several times if necessary) while asking the trainees to write down in detail the steps taken by the installer.

The trainees should come up with the steps indicated on **pages 48 to 49 of the Paper Tool.**

Ask the trainees to define an "ideal Battery box"

Conclude by reading page **49 of the Paper Tool** "The ideal battery box will have the following characteristics."

4.4 Regulator installation procedure – charging the battery

Use the section '*Regulator Installation'* in the Video '**Installation of Small Solar Systems**'. This section lasts only about 1 minute.

View the video (several times if necessary) while asking the trainees to write down each the step taken by the installer.

The trainees should come up with the steps indicated on **pages 50 and 51 of the Paper Tool.**

4.5 Load installation and cabling procedure

Use the section '*Loads and Cables Installation*' in the Video '**Installation of Small Solar Systems**'. This section lasts about 4 minutes.

Read with them **pages 52 and 53 of the Paper Tool.**

Ask the trainees why it is good to paint the ceiling and walls in white rather than with a dark colour?

The answer is: When painted in white, the ceiling and walls reflect the light and gives the impression of a room which is well lit. Tell the trainees that it is also a good idea to paint an area just around the light if the client does not have enough money to paint the whole ceiling.

In practice, the sockets are always one of the first components in a PV system to be 'uninstalled' by the client or the user. Ask the trainees why.

Answer: People (the clients) pull the male socket (the plug) out of the female socket without holding the female socket. There are 2 solutions to avoid this problem: 1. fix the socket firmly to the wall during installation and 2. show the client how to remove a male socket from a female socket carefully.

4.6 The finishing touches for installation

Ask the trainees what remains to be done for the system to function "Is this system installation completed?"

Use the section '*The Finishing Touches*' in the Video '**Installation of Small Solar Systems**'. The duration of this section is approximately 3 minutes.

View it (several times if necessary) while asking the trainees to write down in detail what the installation team is doing.
They should come up with the steps indicated on **pages 54 and 55 of the Paper Tool**

Ask the trainees to develop their own “USER NOTICE.”

They can use the User Notice in **Annex 6 of the Paper Tool** as a reference.

4.7 Teaching video and Paper Tool: what are the differences?

After having shown the videos phase after phase, show the complete video ‘‘*Installation of Small Solar System’*
Ask them to point out the differences in the installation phases between the video (made in 2003) and the procedures as written in the Paper Tool (2008):

Answer lies below:

Video (2003)	Paper Tool (version 2008)
All components (including the cabling of the appliances) of the solar system are installed before the solar charging of the battery. The battery is put to charge in the final phase « Finishing touches ». This does not allow the battery to be charged while the rest of the installation is being completed.	The PV generator is wired (PV module, battery and regulator), and immediately after this step, the battery is put to charge by the PV module (during the step : installation of the regulator – battery charging) This improved method allows the technician and the user to observe the regulator indicators and to charge the battery for a few hours or a full day before the system is used, while the appliances are installed.

4.8 Necessary tools for installation work

Ask the trainees to make a list of all the tools they would need to a carry out an installation.

Use **page 80 of the Paper Tool** to finalise the list.

Make a poster with the trainees about the tools they need for installation.

This poster will be completed when the Module on Maintenance will be taught.

5 Assessment and Feed-back

This section is for the Trainers to ensure that Trainees have understood the main concepts presented in this module.

Organize teams of two or three technicians and ask them to install a small lighting system (e.g. 20 Wp, 2 lamps and one socket with a DC-DC adapter).

- The trainees must write down the list of equipment they need (including the tools) using the **Paper Tool.**
- Trainees must then prepare their solar equipment and tools - and they will NOT be allowed to go back for anything that may be forgotten (as if they were installing systems in a rural area). If they have forgotten something, they will lose points.
- The installation work should strictly follow the **Paper Tool** procedures.
- These installations should be done under strict supervision of the Trainer to ensure that all the procedures are followed (including the "Finishing touches on the installation").

Installation can be done on a real site (a real client in a rural area) or alternatively can be made on a large wooden board (2 m x 1 m) at the training site.

Important note : if the training course is to result in the qualification of trainees for a certain level, **it is suggested to control the work being done with the same rigor that will be used on the examination day**.

This has the advantage of preparing the trainees for the final qualification examination and evaluation[1].

[1] Examinations should not be conceived to lead to failure: they should be a true measure of knowledge acquired.

MODULE 11 : Maintenance and servicing of small solar systems

1 Objectives

This module details the following:

- How to maintain a complete small PV system including:
    - the module(s),
    - the battery,
    - the regulator,
    - the loads,
    - the cables and finally
    - the user or the client!

- Solar system troubleshooting.

2 Module duration

6 to 10 hours

3 Necessary teaching equipment

Description	**Qty (minimum)**
A complete PV lighting kit	1
Set of PV modules of various peak power	1
Set of old PV components, especially old batteries	1
Solar calculator (one per student)	1
Multimeters	5
If possible, have a video that show maintenance being done on a solar system (and have necessary equipment to watch it - TV and VCR)	**1**

4 Content

4.1 *Definition of maintenance*

Ask the trainees if they have any ideas about what the maintenance of a solar system entails?

The concise answer is:
Servicing and maintenance are all the preventive measures to ensure reliable and long lasting systems. There will be less breakdowns.

There are two levels of maintenance (read **page 56 of the Paper Tool**)

4.2 *Maintenance procedure / steps*

Similar to the installation work, it is strongly advised to follow a step by step approach when performing the maintenance tasks.

Phase 1	Prepare your work (with your toolbox at hand)	**Page 57 of the Paper Tool**
Phase 2	Inspect the PV modules, regulator, battery, etc.	**Pages 58 - 67 of the Paper Tool**
Phase 3	Proceed to the finishing touches (including the user training	**Pages 68 - 69 of the Paper Tool**

Suggested teaching techniques:

For each Phase, ask the trainees to list the tasks they think are necessary, and then read with them the written steps in the Paper Tool (2 pages per step - from page 57 to 69).

For example: For "PV module servicing procedure",

1. ask the trainers what they think is necessary to maintain the modules
2. read the page 58-59 that list the 10 steps.
3. **after each step or procedure, practice the actions proposed**

4.2.1 Additional suggested exercises

Ask the trainees to do several PV modules comparison tests (see **page 61 of the Paper Tool**). Be sure you practice these tests when the irradiance is high (solar power – irradiance above 500 W/m²).

It is important that trainees understand this test.

Ask the trainees to practice the regulator threshold voltages checking using a small 4 Ah or 7 Ah 12 V sealed battery (see **page 65 of the Paper Tool**).

It is important that trainees understand this test. Repeat as many times as it is necessary.

4.2.2 Measuring battery capacity

If the battery shows signs of weakness, it is a good idea to test its remaining capacity.

Ask the trainees how they should proceed to test the capacity of a battery?

The answer is:

1. *Charge the battery fully (100%). It will be fully charged when the open voltage (after resting 30 minutes) is around 12.7 to 12.9 V and the electrolyte specific gravity is around 1.24 or 1.28 (according to the battery type). This charging may be done in a workshop or on site*
2. *Then discharge the battery with a discharge rate close to the average current consumed by the client (e.g. 4 lamps of 8 W, that is a current of 2.66 A) or a discharge current for which you know the corresponding capacity C_n. (e.g. 5 A for a battery 50 Ah C_{10}.).*
3. *Measure the current drawn and the voltage every hour and record.*
4. *Stop the discharging when the voltage under load is 10.5 V.*
5. *When the battery has rested for at least 30mn, measure the open voltage. If Uoc is 11.6 to V or 11.8 V, the battery is probably completely discharged. It is a good idea to measure the electrolyte specific gravity as well. It should be around 1.12.*
6. *Calculate the capacity by multiplying the average current x the total discharge time (A x h).*
7. *Do not forget to recharge the battery after the test or you will severely damage it !*

Measurement of battery capacities for several available batteries (de 4 Ah à 100 Ah) with the method proposed above.

Important note: Measuring the battery capacity very accurately is complex. The proposed method above, however simple, can give significant information to help diagnose the state of health of a battery.

4.2.3 Specific gravity measurements in the field

Electrolyte specific gravity (or density) depends on the battery state of charge (SOC) as well as on the temperature.

The hydrometer has been calibrated for a certain temperature (often 20°C), so it may be necessary to make a temperature correction if the electrolyte temperature is very different from 20°C. This corrected value will be used to give a better idea of the battery SOC

A typical correction factor is 0.0007 for every °C.

If temperature electrolyte > temperature calibration	→	add 0.0007 for every °C
If temperature electrolyte < temperature calibration	→	retrieve 0.0007 for every °C

E,g. If the hydrometer has been calibrated at 20°C and one measures 1.22 when the electrolyte is at 40°C, the specific gravity at 20°C is 1.22 + (0.0007 x 20) = 1.234. This value will be used to read the state of charge on the curve SOC/density.

E,g. If the hydrometer has been calibrated at 20°C and one measures 1.22 when the electrolyte is at 10°C, the specific gravity at 20°C is 1.22 – (0.0007 x 10) = 1.213. This value will be used to read the state of charge on the curve SOC/density.

4.3 Typical or recurrent problems and solutions

Ask the trainees why it is important to repair a fault on a system as soon as possible.

The answer is:

1. *To satisfy the client.*
2. *To avoid battery failure. Indeed, even when the faulty component is not the battery itself, most other faults will lead to its premature failure. It is therefore important to ensure that any component fault is corrected as soon as possible.*

4.3.1 Some ideas to help you go through this subject

For each of the following problems related to each component (module, battery and regulator), listed in the **Paper Tool from page 71 to 77**, do a practical exercise. For example: Make some shade on a module (without the trainees looking at you!) and let them find out what is wrong with the system.

Be as imaginative as possible when demonstrating common faults.

4.3.2 Access to good quality distilled water

It may be a problem to obtain good quality distilled, or de-ionised water.

Over the life of a vented battery, the total volume of distilled water added may be much higher than the original volume of water mixed with sulphuric acid (the electrolyte).

The level of impurities in the distilled water for topping-up should be very low since impurities will accumulate and concentrate as water is lost during gassing. Most impurities increase the rate of self-discharge.

In all cases, try to purchase distilled water from battery suppliers or manufacturers. These bottles must be sealed. You may also be able to buy distilled water from laboratories or hospitals. Alternatively and exceptionally, you may replace manufactured distilled water by :

1. Rain water is good quality distilled water, providing it has colleected in the following conditions.

    – Do not collect the first rain, wait for the rain to clean the sky
    – Collect the rain water through a plastic collector such as a large plastic basin. Do NOT use the run-off from any roof surface
    – Store the water should be stored in a clean and closed plastic or glass container with a cap. Water should never be stored in steel or galvanized containers as this will ionize the water.

2. Distilled water can also be made over a fire using a small makeshift 'still'.
    – Boil water.
    – Collect the steam directly in a plastic or a glass container.
    – Attention should be paid to avoid any contamination of the distilled water produced.
    – Store the water should be stored in a clean and closed plastic or glass container with a cap. Water should never be stored in steel or galvanized containers as this will ionize the water.

4.4 Troubleshooting exercise

Game, yes a game!

Ask the trainees to wire a solar system (or several systems) with all necessary electrical protection (fuses or circuit-breaker).

Ask a group of trainees (group A) to create a fault on a PV system and let the other group (group B) find the fault and then explain how they found it. When the group has found a fault and repaired it, they earn one point.

In all cases, the trainer must supervise the faults created (to avoid any short-circuits)

Rotate the groups, the trainees of group B have to create a fault and group A has to find it.

One may complicate the game by creating 2 faults at a time (at a latter stage).

Examples of faults to be created (Usually, trainees are extremely prolific at creating faults).

1. Dirt on the PV module with dust.
2. Put a large piece of cloth on a PV module (shaded module).
3. Modify the orientation of a PV module.
4. Modify the inclination of the PV module.
5. Create a short-circuit on one PV module by-pass diode
6. Create a short-circuit on both PV module by-pass diode (ensure that the regulator can support this fault)
7. Place a fully discharged battery instead of a charged one.
8. Replace a good battery by various ‘dead’ ones (this is usually a lot of fun).
9. Cut cables, but hide where it is cut (watch out to cut one wire at a time to avoid short-circuit) – Cut cables everywhere on the circuit, but only one at a times to avoid confusion.
10. Remove a fuse in the fuse holder.
11. Replace a good fuse by a ‘burnt’ one.
12. Tighten a cable on the insulation material.
13. Replace a good fluorescent tube by a bad one.
14. Replace an incandescent bulb by a bad one.
15. Place a bad regulator instead of a good one (even a regulator with no circuit board inside).
16. Replace a good section cable by a very thin one (hide it of course).
17. Increase by two to threefold the length of a cable to a load (hide it of course).
18. Be creative….do create faults that are realistic!

After practicing some of these faults, ask the trainees to write the down the winning methodology to find faults in a solar system.

5 Assessment and Feed-back

This section is for the Trainers to ensure that Trainees have understood the main concepts presented in this module.

It is suggested to organize teams of 2 to 4 trainees that will have to perform maintenance tasks on a a solar system, and also to practice troubleshooting (this exercise can also be done on a individual basis):

- Ask the trainees to prepare a list of equipment and tools and proceed to maintenance tasks as per the procedures of the Paper Tool, including "maintenance of the user": user training.
- Ask the trainees to enumerate the most frequent problems for each component of a solar system.
- Ask the trainees to explain how they can get hold of quality distilled water
- Ask the trainees to practice troubleshooting (at least 5 problems per trainee).

The trainer supervision is of utmost importance to check that the procedures are being strictly followed

This assessment can be done on a real solar system or on one installed on a wooden board.

Important note : if the training course is to result in the qualification of trainees for a certain level, **it is suggested to control the work being done with the same rigor that will be used on the examination day**.

This has the advantage of preparing the trainees for the final qualification examination and evaluation[1].

[1] Examinations should not be conceived to lead to failure: they should be a true measure of knowledge acquired.

MODULE 12: After-Sales Service

1 Objectives

The learning objectives of this module are:

- how to choose the right tools and spare parts,
- introduction to After-Sales services
  - different aspects of After-Sales services,
  - contractual issues,
  - practical issues,
  - promotion and evaluation.

2 Module duration

2 to 4 hours

3 Necessary teaching equipment

Description	**Qty (minimum)**
Set of tools for installation and maintenance	1

4 Content

4.1. Tool list

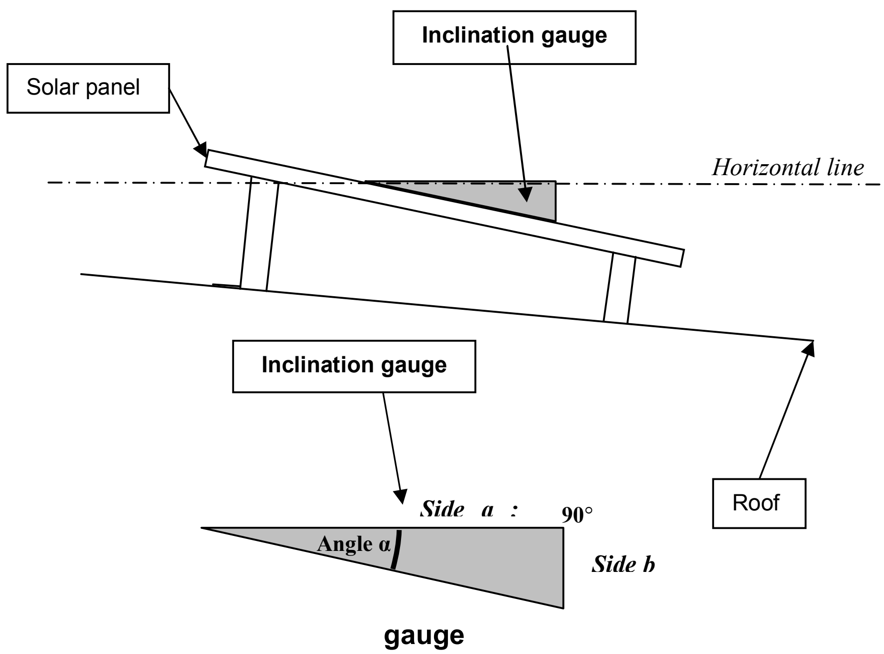
Have trainees make a list of the tools they need for carrying out maintenance on solar systems. Ask them to categorise these tools by order of importance (essential tools, useful but not indispensable tools, and helpful, but not always necessary tools).

The list should be similar to the one on Page 80 of the Paper Tool.

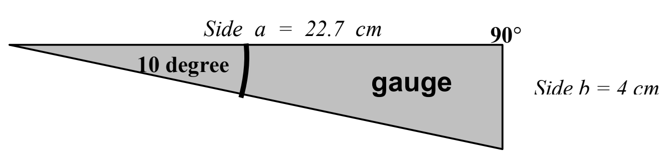
In some cases, other tools such as a DC clamp-meter may be required. Some tools may need to be fabricated by the technicians themselves, such as the tool below.

4.1.1 Making an inclination gauge

The simplest and easiest way to make an inclination gauge is to cut a triangle from a wooden plank according to the drawing below:



The size of the triangle is calculated from the following trigonometric law: **tan α = b / a.**
For example, if the module should be inclined to 10° from the horizontal, tan 10° = 0.176.
If *side b* is chosen to be 4 cm, then *side a* = side b / tan 10° = 4 / 0.176 = 22.7 cm.



With a spirit level on the gauge, it is necessary to verify if the module is well inclined. When the spirit level indicates horizontality, the module is well inclined (e.g. at 10°).

4.2 Spare parts and consumables

4.2.1 Definition: Spare parts

Spare parts are those systems components that are replaced in the course of usual wear of the system (e.g. blackened fluorescent tube after 4 years or an old battery at the end of its life). They can also be parts needed for sudden breaks in the system such as a broken lamp with a manufacturer's default. Spare parts are also indispensible when expanding or rehabilitating a system.

4.2.2 Definition: Consumables

Consumables are smaller system components or materials that a technician will need in order to complete an installation or carry out maintenance. Among the things needed in particular are distilled water, Vaseline, cleaning rags and insulating electric tape, etc.

> Ask trainees to make a list of spare parts that they should keep handy to be able to do most repairs.
>
> *The answer is:*
> *The type and quantity of spare parts depends on each type of system. However, the technician should also have handy solar system spare parts (such as lamps, tubes, switches, etc.) and various consumables such as fuses, petroleum jelly, distilled water, extra cables and connector strips.*

4.2.3 How to define the quality and quantify the spare parts and consumables

The spare parts should be:

- of the same quality as the equipment being replaced (if the parts are of lower quality, the client should be informed about it and pay less for it),
- of the same current or power rating as the replaced apparatus (e.g. lamps, regulator, switches, fuses, or any electrical appliances),
- affordable,
- available after reasonable delays, and
- disposable with minimum effects on the environment.

The necessary quantities of spare and consumable parts depend on the following factors:

Influences	Comments
▸ Clients' demands	Does the client want the system repaired immediately or can she wait a few days to receive cheaper parts?
▸ Type of system	Lighting systems, refrigerators, audiovisual appliances.
▸ Age of the system	The older the system components, the more likely spare parts become necessary.
▸ Number of systems	Quantity will increase with the number of systems to maintain.
▸ Number and type of probable and frequent breakdowns	E.g. : fluorescent tubes.
▸ Distance between technician's workshop and the systems	The greater the distance to the site, the more spare parts should be planned on site in case of need.
▸ The technician's logistical and financial means	A technician is limited by the means of transport at his or her disposal : car, bicycle, bus, etc.

4.2.4 Management of spare parts and consumables

This table should be adapted for each field case according to the specifics of the programme that the technician is responsible for. The table below is a programme with lighting systems:

Description	Spare parts		Consumables	
	Workshop	Field visit	Workshop	Field visit
PV Module PV	✓			
Battery	✓			
Regulator	✓	✓		
Lamp	✓	✓		
Fluorescent tubes	✓	✓		
LEDs	✓	✓		
Lamp holder	✓	✓		
Switches	✓	✓		
Male and female socket	✓	✓		
Cables 2 x 2.5 mm^2	✓	✓		
Nuts and bolts	✓	✓		
Connection boxes	✓	✓		
Connection box	✓	✓		
Fuses	✓	✓		
Locks	✓	✓		
Distilled water			✓	✓
Rags			✓	✓
Vaseline			✓	✓
Electric tape			✓	✓
Plaster / cement				✓
Paint, detergent				✓
User's Manuals				✓

The '✓'s can be replaced by the quantities needed in the field.

4.3 After-Sales service

Rural electrification through Solar PV is becoming increasingly established worldwide in general. With the increasing number of systems (and their ageing), After-Sales Service will eventually become a full-time activity.

Providing After-Sales Services is a good means for a technician or a PV supplier to distinguish him or herself from others in the solar PV market.

Ask the participants what they think After-Sales Services are, in general and in particular.

The answer is: After-Sales Service is the term used to describe the kinds of services provided to the client after the product had been sold and delivered.

It is also the development of a skilled labour force combined with available affordable spare parts at a reasonable working distance from clients.

4.3.1 Key players

Description	Comments
Client	The most important key-player, no other key-players would exist without the client. There would be no reason for After-Sales Services without the client.
Technician	Person with a certain level of technical skills and knowledge about Solar PV system installation and servicing. It is best if a technician also has the quality of entrepreneurship (a good business sense/attitude).
Retailer / supplier	National or local supplier of solar PV systems to the customer (i.e. through an installer).
Wholesaler	Importer of larger quantities of PV components to a supplier. Some systems or components may be produced nationally or regionally.
Manufacturer	Producer of PV systems and components. Most are large multi-national companies which export all over the world. However very good products may be produced regionally or nationally and these products may be easier to procure for after sales services.

4.3.2 After-Sales Service : 5 activities

1 - Warranty
Based on information from manufacturers, suppliers will specify the period of warranty together with a list of items covered under the warranty. According to a warranty's timeframe and conditions, equipment may be replaced free of charge. However, the labour costs associated with a repair may or may not be free of charge for the client.

2 - Servicing or advanced maintenance
Apart from the basic and regular maintenance performed by the user, servicing by a technician should be performed at least once a year or better, every 6 months.

3 - Repairs
When a system breaks down, it is important that a client knows who to call. Usually, a technician will perform the repair work.

4 - Monitoring – Evaluation
The estimations of the costs of maintenance and repair are not always reliable. It is good practice to keep a careful record of all costs incurred during maintenance and repair work.

The technical work related to After-Sales Service also needs to be documented. This information should be recorded on a specific form (see an example at the end of the Module).

5 - Opportunity identification
If the client is satisfied with the system, it does not necessarily mean that he/she has no other needs or wishes. The technician should always propose ways to improve or up-grade the system.

4.3.3 Tasks and Responsibilities in After-Sales Services

Description	**Tasks of the Technician**	Tasks of the Supplier
1. Warranty	Liaison/Link between the client and the supplier. Removal and testing of faulty equipment and installation of replacement parts as per the warranty.	Provide clear information about the conditions and limitations proposed in the warranty. Honour the warranty (in collaboration with the manufacturer). Use the technician's services for carrying out work related to warrantees.
2. Maintenance	Demonstrate best practice when carrying out maintenance visits. Train system users to use their systems well according to their capacity.	Clearly inform about and insist upon the necessity of regular maintenance and servicing. Promote the creation of a network of trained rural technicians for carrying out servicing and repair work. Ensure the availability of spare parts.
3. Repairs	Repair breakdowns on site or in your workshop as quickly as possible.	
4. Follow-up and evaluation	Interact with the client to know more about the system. Gather information about systems (frequency and types of breakdowns) and communicate these to your supplier.	Provide technical tools (measuring devices, record forms, etc.). Keep technicians regularly informed about product performances and any anticipated problems. Evaluate and train technicians.
5. Marketing	Create good relations with the client. Propose and sell new services and products	Inform technicians of new products coming on the market.

4.3.4 After-Sales Service contract (oral or written)

After-Sales Service tasks can be carried out on an ad-hoc basis or can be formalized through a contract between the client and the service provider:

- For a few small solar systems, ad-hoc basis arrangements may be preferred in rural areas between the client and the technician (i.e. word of mouth). They can be simpler to set-up than written contracts which necessitate client literacy and a reasonably high income.
- In the case of many small solar systems (e.g. at least 50) concentrated over a given geographical area, written contracts can be signed between a PV technician and the clients. The clients can be represented by a well informed client, if necessary.

An oral or a written contract should be as detailed as possible to cover any issues that may arise. This is to protect both the interests of the technician and the interests of the client.

4.3.5 Example of and After Sales Service Contract

An After Sales Service contract should be precise so as to cover the interests of all parties; the client, supplier and the technician. The following proposal gives an idea of the types of information which can be found in such a contract; the proposal is not exhaustive.

Sample After Sales Service Contract

- Name and addresses of all parties: Client / Technician / Supplier
- Summary description of services provided (choose one or both):

	Type of Service	Included (labour and transport costs)	Excluded
1	Maintenance of a solar system for an annual fee	Biannual visits (maintenance of solar modules, regulator, lamps and batteries)	Replacement costs of faulty parts
2	Basic repairs of a solar system for an annual fee	4 free repair visits per year (including labour and transport costs), excluding breakdowns due to abuse of the system. The repair will be carried out within 5 days of receiving notice of the breakdown.	Replacement costs of faulty parts

- Additional obligations of the service provider:
  - The quality of the replacement parts is similar to that of the original parts.
  - Respect the terms of warranty on the materials
- Obligations of the client:
  - Carries out regular maintenance (cleaning the panels, topping up distilled water, etc.).
  - Respect the prescribed conditions of use of the system (length of use, no unauthorised loads added on).
  - Contact the technician within 3 days following a breakdown.
- General conditions:
  - Duration: 2 years from the date of signature of the contract.
- Particular conditions and rupture of contract:
  - In the case of breakdown due to abuse of the system, repair visits will be invoiced separately.
  - The contract will be broken (made null and void) if the solar system is dismantled and moved to another site.
- Terms of payment:
  - Cash payment due after each biannual visit.
- Description of the system to be maintained in the contract:
  - Location / complete address
  - Technical details of the equipment (serial numbers, etc.)
  - Installation date and up to date inventory / log notes of the system

Signature of all parties, date

End of sample contract

4.3.6 Estimating costs of After Sales Services

After sales services of solar systems in rural areas is not yet very developed, excepting in the cases of larger businesses with dedicated decentralised services (such as the cases of the SSD Yeleen Kura in Koutiala, Mali or Nuon-Raps in South Africa working with the "Fee for Service" concept). After sales services have been also increasingly promoted in programmes run by NGOs or large institutional donors such as;

- Solar Energy for Health Programme in the RDC, funded by the European Union
- PRS Programme (Sahel solar pumping programme) in the Sahel funded by the European Union

All of these programmes with After Sales Services were confronted with many difficulties, the most important being the lack of means of beneficiary populations to pay for such services.

In rural areas that do not benefit from such after sales services, that is to say the majority of rural areas, rural solar technicians have the difficult task of ensuring after sales services through their own means. As such, the costs of after sales services are often too expensive if nothing is done to reduce costs to a minimum.

The costs of After Sales Services include, in particular:

- Labour costs (in the field and administration costs).
- Transportation costs and eventually lodging costs if the site is far from the workshop.
- Replacement parts and consumables costs.
- Forfeit cost of using the technician's equipment and tools.

To limit costs means studying all possible ways to be economical. The most important ways of reducing costs are by:

1. concentrating clients in limited geographic regions (to reduce travel costs).
2. reducing transportation costs by organising your work well.
3. training users to use their systems well.
4. installing reliable materials and components.
5. installing equipment well.

4.3.7 Promotion of After Sales Services

Building up a substantial group of clients in a given region is fundamental. You should not miss an opportunity to increase the number of clients (your market base).

- When installing or repairing a system, propose an After Sales Service contract.
- Publicity (Install a publicity panel at your workshop indicating the possibility of After Sales Services).
- Visit owners of older solar systems to propose After Sales Services to them.
- Communication / frequent interaction with system suppliers to promote your services.

4.3.8 Evaluating After-Sales Services

It is quite important to evaluate the service offered to the client. Evaluation can be done by the technician himself or herself or by a PV supplier.

An evaluation should cover all or most of the following issues:

- Evaluate the field visit and the way in which maintenance or repairs were executed:
  - How much time is there between the report of the breakdown and the repair?
  - What are the costs of the repairs and what is the breakdown of these costs or repairs?

- Evaluate the performance of the systems you care for:
  - Which parts needs replacement/ repair most often?
  - Are the components / parts performing according to their specifications?

- Evaluate the training of the end-users:
  - Do the users have enough knowledge about the system and its maintenance requirements to maintain the system properly?

- Evaluate the micro-financing mechanism and loan repayments:
  - Is the down payment satisfactory? Too high? Too low?
  - Is the loan period satisfactory?
  - Are there problems with making regular payments on the loan?

- Study any trends or developments in the market such as:
  - Demand side: What do people want / need? (which products, what price range),
  - Supply side: What is newly available on the market?
  - Learn about the current status of the market players
  - Determine the real and perceived energy needs of different potential clients
  - Determine the rate and characteristic use of PV in the household, social and productive sectors
  - Study what the thresholds or triggers are to buy a solar system.

4.3.9 Example of an After-Sales Service Form

Form to be used for a visit to a client of a solar system by a technician (to be filled in by the technician)

Name of client :	
Address :	
Telephone :	
Type of System :	
Object of visit :	**Maintenance / Repair / Evaluation visit**

In case of breakdown	
Date of breakdown:	Date breakdown report received:
Description of breakdown by client:	
Description of breakdown by technician:	

Description of intervention (repair and/or maintenance)
Length of visit:

Comments of system user	**Comments of technician**

Costs to client (costs NOT covered under the after sales service contract):

Parts replaced	Unit price	Qty	Total Price	Labour (b)	
				Transportation costs (c)	
				Tools cost (d)	
				Other costs (e)	
Total Parts (a)					

Total cost		(a + b + c + d + e)

Amount received from client: ………...............

Date and signature of client	Date and signature of technician

5 Evaluation and Feed-back

This section is for the Trainers to ensure that Trainees have understood the main concepts presented in this module.

This can be done in several ways.

Suggested activities to be carried out in teams, individually or as an individual session:

- Ask the trainees to define the notion of "After-Sales services"
- Enumerate the 5 main activities included in "After-sales services"
- Prepare a list of spare parts, consumables and tools to maintain 100 lighting systems (with 4 lamps and one battery per system)

(Note: this assessment may not be necessary if the exercises in previous sections have been successfully completed by the trainees.)

Important note:

Important note : if the training course is to result in the qualification of trainees for a certain level, it is suggested to give similar exercises as those that will be given on the examination day.

This has the advantage of preparing the trainees for the final qualification examination and evaluation[1].

[1] Examinations should always be conceived for success, and not to lead to failure.