Universal Technical Standard for Solar Home Systems

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SUMMARY

3. SHS Standard

1. INTRODUCTION

Field experience with PV rural electrification has shown that the performance of solar home systems SHSs is not always entirely satisfactory. However, in-depth studies of the problems encountered in existing installations have revealed that the pure solar part, i.e. the PV generator, rarely fails. The PV system is often initially blamed for the failure but, when things go wrong, it is usually the other PV system components or the appliances which are powered by the PV generator which are found to have failed. This is mainly because, while PV modules are highly standardised and certified using internationally validated procedures, there are no equivalent standards and procedures available for balance-of-system components, component matching or installation quality, even though the quality of these components has a dramatic influence on user satisfaction and operating costs.

This report results from work which has been funded by the European Commission under Thermie B contract (ref SUP 995 96), and is designed to form the basis for a Universal Standard for Solar Home Systems. It is based on a world-wide review of existing technical standards for SHSs (see Annex 1), which has revealed a large number of inconsistencies[1] between these standards. In particular, different approaches have been found for system sizing, and for specifying types of PV modules, the number of cells in PV modules, types of battery, charge regulation voltage set points, operational information for users, voltage drops, safety measurements and ballast, cables and connectors requirements.

In preparing this report, each of the different approaches has been assessed using scientific reasoning, empirical evidence and the personal experience of the authors. To a large extent, the standard proposed here can therefore be considered as Universal, because each of the existing standards has provided extremely valuable inputs. Moreover, a first draft version has been circulated amongst a wide number of experts from different countries (see Annex 2), and their invaluable comments have also been taken into account.

In parallel with the above mentioned review of existing standards, an enquiry was carried out to identify the concerns of key persons involved in PV rural electrification programmes, and to seek their views on the usefulness and implementation possibilities of a Universal Standard for SHSs. The need for flexibility, which would allow it to be adapted to the particular conditions of each country (climate, local manufacture, internal market, indigenous capabilities, etc.), has been the most outstanding demand. In order to meet this demand, the requirements presented in this standard have been classified into three categories: Compulsory, Recommended and Suggested.

Compulsory requirements (**C**) are those which could directly affect safety or reliability. Failure to meet these requirements could lead to personal injuries or to SHS failure, and they are therefore intended to constitute a minimum core of requirements which must be fulfilled anywhere in the world.

Recommended requirements (**R**) are those which would normally lead to system optimisation. Most of these requirements are universally applicable, and failure to meet them would normally lead to a cost increase. However, because economic considerations can depend on local conditions, the application of these requirements must be reviewed for each particular case.

Suggested requirements (**S**) are those which might be expected to produce a sound installation. However, it should be noted that any judgement of soundness is essentially subjective, so the suggested requirements given here may have been influenced by the personal experience of the authors, and their applicability should also be reviewed for each particular case.

(Note: The symbols **C**, **R** and **S** are used in this document to specify the compulsory, recommended and suggested character of each recommendation, according to the above classification.)

This proposed Standard is intended to provide a basis for technical quality assurance procedures, to the extent that meeting the specified requirements will produce a SHS that will perform adequately. In particular, it is intended to provide a quality reference for procurement specifications issued by National Governments, donors and investors. In addition, it is intended to be useful as a design guideline for SHS manufacturers and installers. The Universal nature of the standard must also be stressed, because the more widely it is adopted, the more benefits there will be for PV users, the PV industry and the general credibility of the PV sector. In international markets, to rely on widely accepted certification procedures is a general sign of technological maturity, and the conventional electricity sector, which uses IEC and VDE standards, is a good example of this.

Systematic quality assurance procedures must include several steps, namely: definition of component and system standards, definition of laboratory tests, testing of prototypes or samples in accredited laboratories, and on-site quality control of systems. In accordance with the Thermie-B contractual conditions, the present report is restricted to the definition of a standard for SHSs, while definition of testing procedures remains for future work[a]. However, it is important to mention that the need for the next steps has been considered

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[a] See note at the end of the introduction

when writing this standard, so the possibility of adding test procedures to the proposed requirements has been present in the authors' minds.

It must be stressed that this standard has been restricted to purely technical aspects. Other items such as guarantees, documentation, spares, labels, etc. are also essential to the success of PV rural electrification programmes and user satisfaction. However, they are largely influenced by the particular local conditions (maintenance schemes, local skills, etc.) and are therefore not suitable for universal standardisation.

This report has been divided into two main Sections:

Section 2 contains a discussion of SHS performance which provides the basis for deriving and classifying the requirements.

Section 3 presents the requirements in a formal way which is suitable for use in contract documents for PV rural electrification programmes. For this, they are classified under three headings, namely: *System, Components* and *Installation*.

Note: Once a reference for the length of cables and the number of lamps has been defined, the requirements for *systems* and *components* can be checked using prototypes. However, the requirements for *installation* have to be verified on site.

The work, which has been carried out to develop the requirements given in this "Universal Standard", has confirmed that technical solutions to the problems addressed differ substantially from country to country. A conscious decision has therefore been taken to use a number of general (rather vague) terms, such as "adequate fixing", "widely acceptable", etc. in the requirements, and it is suggested that quality assurance procedures based on this Standard should make provision for using the subjective opinions of experts when judging whether these requirements have been fulfilled.

It might be considered that the use of such general terms will open the door to controversy, and hinder the application of the procedures. However, past experience with large scale PV programmes has shown that an element of "experts judgements" in quality assurance procedures can provide an appropriate degree of flexibility and can lead to substantial improvements in the cost / quality ratio for the PV systems concerned[2,3,4].

Note to the second version

All the modifications introduced in this new version, with respect to the previous one, have been explicitly indicated by means of foot notes, both in section 2 and in section 3.

These modifications are the result of the work carried out in the framework of the project entitled "Certification and standardisation issues for a sustainable PV market in developing countries” funded by the JOULE III programme of the Commission of the European Union. This project, developed from July 1998 to June 2001, allowed the realisation of a wide experimental campaign leading, on the other hand, to the definition of methods for testing PV systems and components and, on the other hand, a wide inspection of the state of the art in the current market, through the test of almost a hundred equipments.

2. SPECIFICATION FOR SHS COMPONENTS AND PERFORMANCE

SHSs generally have a common design, and consist of the following components:

- A *PV generator* composed of one or more *PV modules*, which are interconnected to form a DC power producing unit.
- A mechanical *support structure for* the PV generator.
- A lead acid *battery* consisting of several *cells*, each of 2 V nominal voltage.
- A *charge regulator* to prevent excessive discharges and overcharges of the battery.
- *Loads* (lamps, radio, etc.)
- *Wiring* (Cables, switches and connection boxes)

This classification of components is useful for presentation purposes, and may also be used in a general way. For example, the term *battery* may be used to refer not only to the battery itself, but also to the battery case, the connectors, etc.

Most present SHSs are low power (<100 Wp) and entirely DC. It is also possible for SHSs to supply AC power by using inverters, but cost and reliability reasons normally tend to restrict their use to larger power levels (>200 Wp). For example, where SHSs are intended to target emerging markets with rather strong purchasing power[5]. Definition of specifications for DC/AC inverters is not considered in this standard and remains for future work.

The quality of a particular SHS may be judged in terms of its reliability, energy performance, safety, user-friendliness and simplicity of installation and maintenance. In addition, particularly for large PV rural electrification programmes, it may be important for SHS to be able to operate with different components (from different manufacturers, for example) and different sizes. When assessing SHS, each of these criteria need to be analysed and concrete requirements specified.

In some cases, two alternative requirements may be specified for the same component or system. This normally occurs where there is a choice of technical quality and costs, and the final selection must be made in the light of local availabilities and constraints. For example, the size of a solar battery is expressed in terms of Days of Autonomy, and the Standard proposes ≥ 5 as compulsory and 8 as recommended. This is not a contradiction. It is simply the case that the compulsory requirement represents an absolute minimum, whilst the recommended requirement is a more desirable but also a more expensive solution.

2.1 RELIABILITY

SHS reliability, in the sense of lack of failures, depends not only on the reliability of the components, but also on some other features of the system which can directly affect the lifetime of batteries and lamps, such as size, the voltage thresholds of the charge regulator, the quality of installation, etc. Each component of the system must fulfil similar quality and reliability requirements because, if there is only one bad component in an otherwise perfect system, this will limit the quality of the whole.

2.1.1. PV generator

- ***PV modules certified according to the international standard IEC-61215 or to the national standard of PV modules used by the relevant country. (R)***

This requirement currently excludes thin-film PV modules, although certification procedures for such modules are also available (IEC-61646, SERI/TR-213-3624). Thin film modules are permitted in some projects supported by the World Bank and promising new modules are emerging onto international markets but until now the field experience with commercially available thin-film modules has been rather discouraging[6,7]. Their use in large-scale programmes is therefore still considered to be extremely risky and it is recommended that they should only be accepted if supported by comprehensive long term guarantees.

Some manufacturers systematically include “by-pass” diodes in their PV modules, to protect them against “hot-spot” phenomena. However, it should be noted that the probability of a PV module becoming damaged by “hot-spots” is close to negligible for DC voltages lower than 24 V. Because of this, the use of such diodes is irrelevant in SHS and they are not considered in this specification.

2.1.2. Support structure

- ***Support structures should be able to resist, at least, 10 years of outdoor exposure without appreciable corrosion or fatigue. (C)***
- ***Support structures must withstand winds of 120 km/h. (R)***

Several materials can be used for support structures, including stainless steel, aluminium, galvanised iron with a protective layer of about 30 µm, treated wood, etc.

- ***In the case of framed PV modules, only stainless steel fasteners (screws, nuts, rings, etc.) may be used for attaching them to support. (C)***

It is worth mentioning that frameless PV modules bonded to a frame with suitable adhesive products, while today scarcely used onto SHS market, are performing well in general PV applications and can also be accepted.

- ***Tilt angle should be selected to optimise the energy collection during the worst month, i.e., the month with the lowest ratio of monthly mean daily irradiation to the monthly mean daily load. Generally, constant user load can be assumed. Then, the following formula can be used***

$$\text{Tilt}\,(^{o}) = \max \{ |\Phi| + 10^{o} \}$$

where Φ is the latitude of the installation. (R).

This formula leads to a minimum tilt angle of 10 °, which is sufficient to allow rainwater to drain off the surface. It may also be useful to note that slight azimuth deviations from south/north (+/- 30 °) and in the tilt angle (+/- 10 °) have a relatively small influence on the energy output of a PV array.

Most of the consulted experts are opposed to manual tracking because it implies a risk of damage to the modules, and a risk of energy lost through poor or no adjustment. However, it has been used in some places with positive results not only in terms of energy gain, but also in terms of user participation. Naturally, adequate training is needed and the tracking features, including any hinges and other coupling devices needed to allow the modules to be moved, must also meet the requirements specified above. Hence:

- ***Static support structures are generally preferable to tracking-ones (R)***
- ***In the case where manual tracking (2 or 3 positions per day, moving from East to West) is used, all of its features must meet the support structure requirements specified above (C).***

2.1.3. Battery

For the battery, the most important feature of its operation in SHSs is cycling. During the *daily cycle*, the battery is charged during the day and discharged by the night-time load. Superimposed onto the daily cycle is the *seasonal cycle,* which is associated with periods of reduced radiation availability. This, together with other operating parameters (ambient temperature, current, voltages, etc.) affects the battery life and maintenance requirements. In order to maximise the lifetime of lead acid batteries, the following operating conditions must be avoided[8]:

- High voltages during charging (to prevent against corrosion and loss of water)
- Low voltages during discharge (corrosion)
- Deep discharge (sulphation, growth of dentrites)
- Extended periods without a fully charging (sulphation)
- High battery temperatures (all ageing processes are accelerated)
- Stratification of the electrolyte (sulphation)
- Very low charge currents (sulphation)

These rules lead to specifications for sizing (both battery and PV generator) and for battery protection procedures (charge regulator). However, it must be pointed out that some of the rules are generally in contradiction with each other (e.g. full charging needs high voltages but high voltages accelerate corrosion), so compromises must be found taking into account the particular local conditions: solar radiation, PV module and battery prices duties and taxes, local manufacturing, recycling infrastructure, etc. Perhaps this explains the lack of consensus on this issue among the different information sources (standards, experts, etc.) that have been consulted during the preparation of this standard, and the requirements given below should therefore be adapted to suit the local circumstances.

The need to prevent excessive discharge leads to the need to limit the maximum depth of discharge to a certain value, PD_{MAX}, which usually ranges from 0.3 to 0.6, but can approach 0.8 according to the type of battery. The supply to the load must be cut when this limit is reached. The available or useful capacity, C_U, is therefore less than the nominal capacity, C_{B}, (which refers to the whole charge that could be extracted from the battery if no particular limitations were imposed) and equal to the product $C_{\mathrm{B}}.\ PD_{\mathrm{MAX}}$, such that:

$$\mathrm{C}_U = \mathrm{C}_B.\ PD_{MAX}$$

A good compromise between cost and reliability is typically obtained with a battery whose useful capacity ranges from 3 (in regions where extended cloudy periods are not expected) to 5 (in regions where cloudy periods are expected) times the total daily energy consumption in the house, so that the depth of discharge in the daily cycle, PD_d, ranges from 0.06 to 0.2. The selection of a particular capacity mainly depends on the type of the battery. "Good" batteries are able to resist deeper cycling than "bad" batteries. Hence, for the same application, "good" batteries can be smaller than "bad" batteries, in terms of nominal capacity.

Best quality PV batteries are made with tubular plates and grids with low Sb-Se content. More than 8 years life, with $PD_d = 0.2$ and a maintenance period of 1 or 2 times per year, are attainable with such batteries. A particular disadvantage with tubular batteries for SHSs is that they do not readily accept low rates of charge. They are also expensive and are rarely available in the current markets in developing countries. Nevertheless, they should not be excluded from SHS programmes. On the contrary, it is recommended that large rural electrification programmes should consider encouraging manufacturers to put these products onto the market.

In contrast, automotive batteries, usually referred as SLI[b], have a number of advantages. They are usually the cheapest batteries when compared in terms of nominal capacity (the difference in cost can be 4 or 5 fold), they are often locally produced and are widely available. Local production is not only convenient for economic and social reasons, but also because it represents the best possibility to recycle old batteries and to avoid environmental damage. Their main drawback lies in their relatively short lifetime. Because their cell design is optimised to deliver heavy currents during short periods of time, they have large areas of thin plates, and are poorly suited to supplying smaller currents for many hours before being recharged, as is required by SHS. It is therefore necessary to use larger battery capacities leading to $PD_d \leq 0.1$, and a density of electrolyte which is lower than would normally be used in this type of battery (for example, 1.24 instead of 1.28 g/cl). This is needed to reduce grid corrosion and hence to lengthen battery life. The associated increase in internal resistance in the battery does not represent any problem in SHS, because the charge and discharge currents are relatively low in comparison with conventional battery charge and discharge regimes. *Classical SLI batteries* use lead grids alloyed with antimony and require periodic topping up with water.

The short lifetimes of automotive batteries can also be compensated to some extent by introducing relatively simple modifications to the battery design but not to its technology. The most common modifications are thicker electrode plates and a larger quantity of acid solution in the space above the plates. Such *modified SLI* batteries are sometimes marketed as "solar" batteries and represent a promising alternative for the future of SHSs. Wherever possible, modified SLI

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[b] STARTING, LIGHTING, IGNITION.

batteries should be selected (and local manufacturers should be encourage to make them) in preference to conventional SLI batteries. Certain conditions must be required for a battery to be categorised as “modified SLI”, as follows:

- ***The thickness of each plate must exceed 2mm. (C)***
- ***The amount of electrolyte must exceed 1.15 l per 100 Ah of 20-hour nominal capacity and per cell. (C)***
- ***The separator must be made of microporous polythene. (R)***
- ***The density of electrolyte must not exceed 1.25 g/cl. (S)***

“Low-Maintenance” SLI batteries, sometimes marketed as maintenance-free batteries, often employ grids containing calcium alloys. The calcium increases the voltage at which gassing begins, but reduces the cohesion of the active material to the grids. Hence, it cuts down the loss of water but also reduces the cycle life. Such batteries are particularly vulnerable to damage from deep discharge. In addition, they are also liable to be damaged by high temperature variations. Hence, many PV system designers strongly recommend against their use in PV applications in hot countries. However, the maintenance-free feature is still attractive and extensive use has been made of these batteries in some countries like Brazil[9].

“No-maintenance” batteries are also made for professional applications by using a semi-solid electrolyte (gel or malting). Such batteries, referred as VRLA (valve regulated lead acid), are more often resistant to deep discharges, but they are usually very expensive for SHSs, and they require specific recycling facilities. They are not considered in the present standard although they represent a legitimate technology choice in some cases. The same is valid for NiCd batteries.

When specifying batteries, it should be noted that cycle life testing under representative SHS operation conditions is both time-consuming and difficult. Despite some past attempts, widely accepted test procedures do not yet exist and this situation is likely to remain in the years to come. For this reason, the most practical approach is to rely on well-established battery standards for conventional uses, that means, capacity values corresponding to a discharge of 20 hours and cycle lives corresponding to a depth of discharge of 50%. Once it has been confirmed that the energy production will exceed the demand of the load during the worst month (see 2.3.2), the following rules[10] should be followed for battery sizing:

- ***The 20-hour nominal battery capacity in amp-hours (measured at 20 ^oC and until a voltage of 1.8 V/cell) should not exceed CR times the PV generator short-***

circuit current in amps (measured at Standard Test Conditions). For each type of battery, CR values are proposed in the table below:

Battery type	***CR***	
	Compulsory	**Recommended**
Tubular	20	15
SLI:		
- Classical	40	30
- Modified	40	35
- Low-maintenance	40	30

- ***The maximum depth of discharge, PD_{MAX}, (referred to the 20-hours nominal battery capacity) should not exceed the values proposed in the table below:***

Battery type	**PD_{MAX}**	
	Compulsory	**Recommended**
Tubular	80	70
SLI		
- Classical	50	30
- Modified	60	40
- Low-maintenance	30	20

- ***The useful capacity of the battery, C_U, (20 hours nominal capacity, as define above, multiplied by the maximum depth of discharge) should allow for a three to five day period of autonomy (R)***

The value of *CR* must be low enough to ensure that the PV array is able to provide adequate re-charging of the battery. The recommended ratios *CR* of the nominal capacity C_B to the PV generator short circuit current depend on the battery type, as shown in the Table, and have been chosen to avoid charging currents which are too low for the size of battery used. The size of the battery C_U must also take into account the local meteorological conditions. Obviously, the larger the expected number of cloudy days, the larger must be the size of the battery C_U.

As an example:

Let us imagine a SHS composed of a PV module whose short circuit current, at STC, is equal to 3.3 Amps, with a modified SLI battery. Then

$C_B \leq 40 \times 3.3 = 132$ Ah is compulsory and

$C_B \leq 35 \times 3.3 = 115$ Ah as recommended.

Further, let us suppose that the SHS must provide 12 Ah per day in a rather dry place. Then:

$C_B \geq 12 \times 3/0.6 = 60$ Ah is compulsory and

$C_B \geq 12 \times 3/0.4 = 90$ Ah is recommended.

Hence C_B must be selected as follows:

compulsory 60 Ah $\leq C_B \leq$ 132 Ah,

recommended 90 Ah $\leq C_B \leq$ 115 Ah.

Now consider the same example, but in a place with frequent rainy periods, where the expected number of cloudy days is 5. In this case, C_B may be selected as follows

compusory range of 100 Ah $\leq C_B \leq$ 132 Ah

recommended one of 150 Ah $\leq C_B \leq$ 115 Ah.

(This "recommended" range is physically meaningless, so only "compulsory" range applies.)

It should be stressed that all these capacity values correspond to a 20-hours discharge rate. If other rates are desired, the following empirical relations can be used: $C_{100}/C_{20} \cong 1.25$, $C_{40}/C_{20} \cong 1.14$.

It is important to note that nominal capacities are measured by means of discharge tests carried out after some well standardised charging procedures (i.e. 24 hours at 2.4 V/cell) which ensure the "formation" of the plates. This means that the relevant parts of the homogeneous plate materials used in the manufacture of the battery are converted to lead dioxide on the positive electrodes and to sponge lead on the negative electrodes. Also, the plates of new batteries are often incompletely formed and have large remanents of other materials (SO_4Pb, PbO) which lead to initial capacities that are significantly below the nominal values. This poor formation can normally be compensated by appropriate initial cycles, but in stand-alone PV systems in particular it cannot be assumed that this will happen, because of the intrinsically limited availability of charging current. As a result, good battery technology can be effectively wasted because field programmes are unable to respect the initial charging instructions. Hence, provisions must be made to ensure that the initial capacity of the SHS batteries are not significantly below the nominal values.

This can be done by an appropriate forming process during battery manufacturing, or by performing initial cycles once the batteries are installed. However, if the latter approach is chosen, the people installing the systems must be equipped with the facilities needed to charge the batteries and be trained in the process and control of these initial cycles. Such an approach is normally unsuitable with SHSs, because of their remote operating conditions.

Batteries are often stored and transported without electrolyte inside, and are not filled until the moment of their final installation. This approach offers the advantages of safety during transport and avoiding self discharge during storage, but requires initial cycles (if needed) to be done at the final location of the batteries which is particularly difficult in SHSs, as mentioned before. A good alternative is to store the batteries dry, and to fill them with electrolyte just before they are sent to their final location. This requires the batteries to be transported in a wet condition, but allows the initial cycles to be performed at the headquarters of the PV assembler. Whatever the case it follows that:

- ***Provision must be made to ensure that the capacity of the delivered batteries is not below the 5%[c] of the nominal value (C)***

Finally, and concerning battery resistance to operating conditions, the following specifications are here proposed*:*

- ***The cycle life of the battery (i.e., before its residual capacity drops below 80% of its nominal capacity) at 20°C, must exceed a certain number of cycles, NOC, when discharged down to a depth of discharge of 50%. For each type of battery, a NOC value is given in the table below (R)***

Battery type	NOC
Tubular	600
SLI	
- Classical	200
- Modified	200
- Low-maintenance	300

- ***The self-discharge rate of batteries, at 25°C, must not exceed 6% of their rated capacity per (month (C)***

2.1.4. The charge regulator

The charge regulator serves primarily to protect the battery against both deep discharging and overcharging. It is also used to protect the load under extreme operating conditions, and to provide operational information to the

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[c] There was a mistake on the compulsory percentage in the previous version.

users. Ideally, charge regulation should be directly controlled by the state of charge of the battery, and sophisticated charge regulators based on that principle are available in the current market. However, they are still rather complex and expensive, so their use in small SHSs is scarcely justified. For this reason, only charge regulators which are based on voltage control are considered in this standard.

Typically, charge regulators account for only about 5% of the initial investment cost of a SHS. However, their impact on the total long term cost of a SHS is much larger than this, because batteries can easily become the largest component of the life cycle cost of the system, and the battery lifetime is directly linked to the quality of the charge regulator. For this reason, good quality charge regulators should be used, and they should have a design lifetime of at least 10 years.

In order to protect the battery against excessive discharge, the load has to be disconnected when the battery voltage falls below a certain threshold, named the “load disconnect” voltage, and it must not be reconnected until the battery voltage has risen above a higher threshold, named the “load reconnect” voltage. The existing standards are rather inconsistent concerning the values of such thresholds, but this is not surprising because the electrical behaviour of batteries depends not only on the particular battery design and manufacturing process, but also on battery age.

In practice, the selection of the load disconnect voltage involves a trade-off between a satisfied user (low load disconnect values to maximise energy availability) and protecting the battery and other equipment (high load disconnect values). Field experience has shown that very protective algorithms tend to encourage undesirable practices such as the bridging of charge regulators. In the light of such experiences, the use of warning lights, alarms, re-set buttons, etc. to warn the user about the risk of disconnection is attractive. Several different combinations of warning system and deep-discharge protection are now available on the market.

When discussing particular specifications, it should first be mentioned that experiences provided by the different experts that have been consulted during the drafting of this standard are very different. In consequence, their recommendations also differ. For example, the better accepted systems in India (currently by far, the biggest world-wide SHS market) possess a “wedding by-pass”. This by-pass facilitates easy switching by the user to accommodate special needs on special occasions. The expert from India believes that failure to provide this facility, which is a strong marketing feature, encourages tampering with the system. Hence, he recommends this standard should not exclude this provision. Similar reasons and also security concerns (i.e.: snake’s sting at night) have led in the past to the inclusion of a manual release for the deep-discharge protection in the Mexican PRONASOL programme (by far, the biggest PV rural electrification programme world-wide). However, the manual release has recently been excluded from this programme, because it has been widely abused (many users just release the protection all the time).

Following this discussion, it should be noted that all means of protecting the equipment must be considered in the context of who owns the system and who has responsibility for protecting it. Let us consider some examples outside the PV field. Cars, which are typically privately owned, normally incorporate a simple warning (red light, or similar) for motor overheating, and leave the driver with the decision of whether to stop or not when the light comes on. In this case, the driver is also fully responsible for the consequences of a possible motor breakdown. In contrast, grid-connected houses normally incorporate overcurrent protections that automatically disconnect the load, without any user intervention, once certain limits are reached. These serve, in fact, to protect the grid, which is owned and must be maintained by the utility company.

Protection of the equipment should also be considered in connection with the energy consumption standards which are defined for design purposes in section 2.3.1. Small standard system sizes can be expected to lead to high frequencies of deep discharge events and, hence, the need for protection but also the tendency to tamper the system.

Finally, the availability of local batteries, their prices and, hence, the economic impact of deep-discharge protection on battery lifetime also differs from country to country.

Whatever the case, there is clear evidence that “load-disconnect” and “load-reconnect” voltages must be specifically adapted to each kind of battery. Discharge capacity tests carried out at the IES with the aim of precisely defining the relationship between cell voltage and state of charge, *SOC*, on several SHS batteries have shown the inadequacy of establishing universal “load-disconnect” and “low-reconnect” voltage values (see table below). Moreover, most of the consulted experts agree on this, even though this approach is still being followed in many current SHS programmes.

	BT1	**BT2**	**BT3**	**BT4**	**BT5**
ρ (g/cm^3)	1,24	1,20	1,24	1,28	1,24
V (v/cell)					
2	56	100	68	40	60
1.95	33	60	30	17	33
1.9	18	28	10	7	17

	BT1	**BT2**	**BT3**	**BT4**	**BT5**
ρ (g/cm^3)	1,24	1,20	1,24	1,28	1,24
V (v/cell)					
1.85	6	7	2	2	6
1.8	0	0	0	0	0

State of charge vs cell voltages of several SHS batteries tested. (In all the cases. $C_{20} \cong$ 100 Ah, I_D = 7 A, T_a = 25°C*)*

Bearing in mind all the above-mentioned uncertainties, the following specifications are proposed here :

- ***Deep discharge protection must be included (C).***
- ***"Load-disconnection" voltages should correspond to the maximum depth of discharge values defined in 2.1.3, when the discharge current, in amps, is equal to the daily load consumption, in amp-hours, divided by 5. (C)***
- ***"Load-reconnection" voltage should be 0.08 V/cell (or 0,5 V per 12 V) higher than the "load-disconnection" voltage (R)***
- ***Manual release of the deep-discharge protection is not permitted (S)***
- ***Warning facilities must be included (R)***
- ***"Warning" voltage (low voltage) must be 0.2V (for 12V systems) higher than the consumption disconnection voltage. (R)***[d] ***should be selected such that the warning signal is activated 30 minutes before "load disconnect" occurs, assuming all the loads are "on"***
- ***"Load-disconnection", "load-reconnection" and "warning" voltages should be accurate to within ±1% (±20 mV/cell, or ±120 mV/battery of 12 V) and remain constant over the full range of possible ambient temperatures (C)***

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[d] This specification modifies the one appearing in the previous version: *"Warning" voltage (low voltage) should be selected such that the warning signal is activated 30 minutes before "load disconnect" occurs, assuming all the loads are "on".*

Electrical loads (appliances) requiring a high starting current (i.e.: motors) can cause the battery voltage to briefly drop below the load disconnect voltage even though the battery still has an acceptable state of charge. In order to avoid an undesirable power interruption in these circumstances

- ***Disconnection of the load should be delayed for between 3 and 30 seconds after the load disconnection voltage has been reached. (R)***

It should be noted that this approach to specifying batteries and charge regulators settings, i.e.: based on the matching of charge regulators settings to battery type, implies that a battery capacity test must be performed at a precise discharge rate for each different battery type. Whilst this is far from the current practice of simply relying on fixed threshold voltages, we believe that the costs of such tests will be largely balanced by the resulting benefits in terms of battery lifetime, even in the case of relatively small PV rural electrification programmes (about 100 SHSs).

To protect the battery from becoming overcharged, the charging current must be limited when the battery voltage rises above a certain threshold, called the “end-of-charge” voltage, and must not be restored until the battery voltage falls below another threshold, named the “reposition” voltage.

Basically, there are two kinds of charge regulators, and the main difference is in the position of the switching device. The “Series” type interrupts the connection between the solar generator and the battery, while the “Shunt” type short circuits the solar generator. In addition, there are two main types of control strategy. In a “Two-step” control arrangement, the charging current is fully interrupted when the end-of-charge voltage is reached. While in a “Pulse-Width Modulation” control, the charging current is gradually reduced at the end-of-charge voltage level, thus keeping the voltage constant. In SHSs, both types of regulators and both control strategies serve well. In fact, recent systematic and independent testing experience[11, 12, 13] does not suggest that there is any real advantage associated with either type of regulator or control strategy, in terms of improvements to battery lifetime.

In practice, the selection of “end-of charge” and “reposition” voltages involves a trade-off between ensuring a full charge (higher voltages) and avoiding excessive corrosion and water consumption (lower voltages). Again, energy consumption standards defined for system sizing purposes play an important role. Low standard values (small system sizes) tend to lead to over consumption rather than overcharging, so charge acceptance should take precedence over water consumption, and higher end-of-charge voltages should be used. Maintenance responsibility and battery prices can also influence the balance of this trade-off.

Ideally, a recharge test should be performed to precisely define the relationship between cell voltage and gassing current. Then:

- ***End-of-charge voltage should correspond to a recharge factor between 0,95 and 1, at a constant current equal to the short-circuit current of the PV generator at the STC. (*****R*****)***

However, it is worth noting that the sensibility of the end-of-charge value to the kind of battery is relatively low (much less than the sensibility of the load–disconnect voltage, mentioned above). Hence, if such tests are not available:

- ***End-of-charge voltage should lie in the range from 2.3 to 2.4 V/cell, at 25°C. (*****C*****)***
- ***In the case of two-step controllers, the reposition voltage should lie in the range from 2.15 to 2.2 V/cell, at 25°C. (*****C*****)***

Constant end-of-charge voltage must be, for regulators controlled by Pulse Waving Modulation (PWM), slightly lower than the one requested for regulators with ON/OFF controls, aiming to reduce water losses and corrosion rate. In all the tested batteries the gassing current measured at 2.4 V/cell is between 50 and 60% higher than the one measured at 2.35V/cell. Corrosion rate is also significantly increased at high voltages, while the charge is kept by maintaining a constant voltage at a proper level. So:

- ***In the case PWM regulators, en-of-charge voltage must be in the range of 2,3 at 2,35V/Cell, at 25°C. (*****C*****)***[e]

Whatever the case:

- ***A temperature correction of -4 to -5 mV/°C/cell should be applied to the end-of-charge and reposition voltage ranges mentioned above.*** *(This specification must be* **C** *only if ambient [indoor] temperatures around the controller are expected to vary significantly during the year, say by more than ±10°C. Otherwise, temperature compensation circuitry is not really needed).*
- ***End-of-charge and reposition voltages should be accurate to within 1% (±20mV/cell, or ±120mV per 12 V battery) (*****C*****)***

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[e] This specification, as well as the previous explanatory paragraph was not included in the first version.

- ***If electro-mechanical relays are used, the reposition of the charge should be delayed for between 1 and 5 minutes (C)***

It is extremely important to note that all the above mentioned voltage thresholds are defined at the battery terminals. Excessive voltage drops (in charge regulators, cables, switches, fuses, etc.) have been shown to be detrimental to the operation of many systems[11], and have typically resulted in a loss of charging effectiveness of the PV generator. Because the charge regulator typically senses the battery voltage at the charge regulator itself, any voltage drop reduces the actual charging voltage at the battery, which can affect its correct operation. Differences of as little as 30 mV/cell in threshold values can have significant effects on the resulting battery state of charge estimation and ultimately on the lifetime of the battery[11]. Similarly, any excessive voltage drops in the load circuit reduces the available voltage to the load. Hence, voltage drops should be limited in both the wiring (see 2.1.6) and the charge regulator itself, for which the following requirements apply:

- ***All the charge regulator terminals should easily accommodate, at least, 4 mm^2 section cables. (C)***
- ***Internal voltage drops between the battery and generator terminals of the charge regulator must be less than 4% of the nominal voltage (≅0.5 V for 12 V) in the worst operating conditions, i.e., with all the loads "off" and the maximum current from the PV generator. (C)***
- ***Internal voltage drops between the battery and load terminals of the charge regulator must be less than 4% of the nominal voltage (≅0.5 V for 12 V) in the worst operating condition, i.e., with all the loads "on" and no current from the PV generator. (C)***

Nevertheless, unsafe battery operation can still occur because of contact faults, etc. For this reason:

- ***The charge regulator can include an independent battery voltage sensor line. (S).***

Some PV system designers recommend the use of controlled overcharges, as a means of avoiding the detrimental phenomenon of stratification of the electrolyte. However, empirical evidence of the real advantages that this can achieve in small SHS is still lacking. This lack of empirical evidence has led to the publication of very different advice concerning the best approach to controlled overcharging. For example: The Fraunhofer ISE suggests that:

- ***Controlled overcharging should be done at a constant voltage of 2.5 V/cell. Overcharging should occur after each deep-discharge and/or at 14-day intervals. Overcharging should last between 1 and 5 hours. (S)***
- ***It should be possible for controlled overcharging to be manually switched off. (S)***

In another example, a European system manufacturer suggests the use of two superimposed voltage hysteresis cycles, where one cycle corresponds to normal operation and is defined by the end-of-charge and reposition voltages explained above while, in the other cycle, the controlled overcharge is regulated by an upper threshold which is higher than the end-of-charge voltage, and a lower threshold which is smaller than the reposition value. In this case, the control automatically moves from one cycle to the other each time that the controlled overcharge thresholds are reached. For this case:

- ***The upper and lower controlled overcharge voltages should, respectively be 2.5 and 2.25 V/cell. (S)***

In all cases:

- ***Controlled overcharging of "low-maintenance" SLI batteries must be avoided. (C)***

It is worth noting that the need for controlled overcharging also depends on the selected end-of-charge voltage. Thus, 2.3 V rather than 2.4 V should be selected for the end of charge voltage if controlled overcharging facilities are provided.

Reverse current leakage protection is usually employed to avoid discharging of the battery through the PV module during the night. Although such discharges are normally not severe, their prevention does help to improve the energy performance of SHS. Reverse current leakage protection is very easy to implement either in "shunt" regulators, by fitting a blocking diode to avoid the discharges of the battery through the switching device or in "series" regulators by using a low cost logic derived method. Hence:

- ***Reverse current leakage protection must be provided (C).***

Unusual service conditions can occur in SHSs. The most potentially dangerous for both the charge regulator and the load is operation without a battery (which can happen when maintaining the battery or when a battery protection fuse blows). Then, if no specific protection is provided, the PV generator imposes the voltage and this can rise high enough to destroy electronic devices. To avoid this:

- ***The charge regulator must be able to resist any possible "non-battery" operating condition, when the PV generator is operating at Standard Test Conditions and with any allowed load. (C)***
- ***The charge regulator must also protect the load in any possible "non-battery" condition, as defined above, by limiting the output voltage to a maximum of 1.3 times the nominal value. (Full interruption of output voltage is also allowed) (C).***

Extremely exhausted batteries also present potentially dangerous conditions, because some charge regulators are not able to operate at very low battery voltages, and therefore can block battery charging. To avoid this:

- ***The charge regulator should allow battery charging from the PV module for any voltage greater than 1.5 V/cell. (R)***

Obviously, to adequately protect the battery, the charge regulator itself must be highly reliable and well protected against damage. It follows that the charge regulator must be able to manage both the maximum current from the PV generator, and the maximum current to the load. Hence:

- ***The charge regulator must resist without damage the operating condition defined by: ambient temperature of 45℃, charging current 25% greater than the short circuit current of the PV generator at Standard Test Conditions, and discharging current 25% greater than that corresponding to the full load "on" at the nominal operating voltage. (C).***

The circuitry also needs to be protected from damage caused by mechanical impact and the effects of adverse ambient conditions (dust, moisture and insects), while allowing ventilation of the regulator's internal components. To ensure this:

- ***Charge regulator boxes must provide protection to at least IP 32, according to IEC 529 or DIN 40050. (C)***

The first IP reference number indicates the degree of protection against contact with solid foreign bodies, and "3" means protection from solid objects (tools, wires, etc.) with a thickness of more than 2.5 mm. The second IP reference number indicates the degree of protection against water ingress, and "2" means that there must be no harmful effects when the equipment (enclosure) is tilted at an angle of up to 15° from its normal position and water drops vertically onto it. IP 32 should be considered as the absolute minimum protection required for charge regulators. If possible, this should be exceeded by reducing the diameter of solid objects to 1 mm and by providing protection against water splashed against the equipment from any direction. In this case:

- ***Charge regulator boxes must provide protection to IP 54, according to IEC 529 or DIN 40050. (R).***

The required degree of protection must be related to the type of installation involved. IP 3.2 can be accepted for indoor installations while IP 5.4 should always be imposed for outdoor installations.

Furthermore:

- ***The charge regulator must be protected against reversed polarity in both PV generator and battery lines. Diode-fuse or other arrangements can be used. (R)***

PV generators typically contain large conductive loops, so protection against over-voltages caused by lightning is also needed. Consequently:

- ***The charge regulator should be protected against induced over-voltages by means of a 1000 W, or greater, transient voltage suppressor inserted between both (+ and -) poles, at the PV generator input. (R)***
- ***The charge regulator should be protected against induced over-voltages by means of a 1000 W, or greater, transient voltage suppressor inserted between both (+ and -) poles, at the load output. (R)***

Suitable protection devices include metal-oxide-varistors, MOV, and avalanche transient voltage suppressors (TVS). Most small PV charge regulators use MOVs because they are significantly cheaper than the other types.

Finally, charge regulators can produce interference, which is harmful to radios and other electronic equipment, for example this can be caused by PWM controllers which are used to limit the current from the PV generator. Hence:

- ***The charge regulator must not produce radio frequency interference in any operation conditions. (C).***

It is worth observing that in the rural areas of many developing countries only AM radio broadcasting is available.

2.1.5. The loads (mainly lighting)

Typical loads in SHSs are lamps, radios and TV-sets, and lighting usually represents a substantial part of the total energy consumption of the house. Lamps are usually included in SHSs kits, but they have not yet been widely standardised. In contrast, radios and TV-sets are directly acquired by the users from the conventional appliances market, their energy consumptions tend to be modest and they are highly standardised products. For these reasons, only lamps are reviewed in this standard, while information concerning radios and TV-sets (low standby losses, protection against reverse voltage, required voltage, etc.) are entrusted to training and general information activities.

For efficiency reasons, fluorescent lamps normally form the basis for lighting in SHSs. The ballast of a fluorescent lamp is essentially an oscillator that has to assure high energy and luminous efficiency and a long lifetime for the tubes. Perhaps, the main difficulty for this lies in the large range of operating voltages at the input of the ballast, which is caused by the unavoidable variations in SHS operating conditions (different battery state of charge, discharge currents, etc.). Unfortunately, to ensure a long lifetime, the tubes need to be fed with a constant voltage. There are some ballasts on the market which include voltage stabiliser stages, and this can be an adequate solution to overcome the above-mentioned difficulty. However, the associated cost is far from negligible because of the need to incorporate an additional transformer.

Specifications for high quality electronic ballasts have been proposed[14], but insufficient evidence is yet available to justify imposing these at this stage and further analysis of field experience and cost optimisation studies are still needed. For example, some ballasts feature preheating of the lamp electrodes, and it is clear that the wave form of the current through the lamp can also affect the lifetime of fluorescent lamps. Most of the ballasts which are currently found in the PV market do not fit with the proposed high quality specifications, and good results have been obtained with rather simple ballasts, if these are carefully adapted to the particular operating conditions of the region. The requirements proposed here are therefore as follows:

- ***Ballasts must ensure safe and regulated ignition in the voltage range from –15% to +25% of the nominal voltage (10.3 V to 15 V for 12 V battery). (C)***
- ***Ballasts must ensure safe and regulated ignition in the range of ambient temperature from –5°C to +40°C. (C).***
- ***Ballasts must be protected against destruction when: (C)***
  - ***⇒the lamp is removed during operation or the ballasts are operated without the lamp.***

    - ***⇒the lamp does not ignite.***
    - ***⇒the supply voltage is reverse-poled.***
    - ***⇒the outputs of the electronic ballast are short circuited.***

- ***Ballasts must not produce radio frequency interference. (C)***
- ***The consumption of ballasts when they are operated without lamps must be lower than 20% of their nominal power. (R)***
- ***Minimum DC power requested at the ballasts input must be 90% of the nominal value of the lamp, in all the range of the operating voltage (-15% to +25% of the nominal value (C)[f].***
- ***Luminous yield for the total ballast and fluorescent lamp system must be at least 35 lum/W[g,h]. (C).***
- ***Luminous yield for the total ballast and fluorescent lamp system must be at least 50 lum/W[h]. (R).***
- ***Luminous yield for the total ballast and fluorescent lamp system must be at least 60 lum/W[h]. (S).***

In view of the lack of a direct relation between the tube lifetime and other electrical parameters, the cyclic resistance of the lamp is proposed to be directly considered as the parameter to be specified and tested. Some steps have already been taken in this direction by the World Bank Chinese project —whose specifications[15] require at least 1000 cycles—, as well by the FISE, whose international procedure requires a minimum of cycles for the lamp to be considered acceptable. While the first is clearly below the current state of the art, the second one tends to be rather restrictive, specially when comparing it to local products. Consequently two new specifications concerning cycling resistance apply[i]:

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[f] This specification replaces the one in the first version: *"Minimum luminous flux for the total ballast and fluorescent lamp system must be 80% of the nominal value"*

[g] Quality of the lamp performance is directly related with the luminous efficiency as a whole, so the test of any other intermediate efficiency is not strictly necessary. Consequently, the specification *"Minimum electrical efficiency of the ballasts must be 70% in all the range of the operating voltage (–15% to +25% of the nominal voltage)", included in the first version, has been eliminated.*

[h] In the first version, values of compulsory, recommended and suggested luminous yield were, respectively, 25, 35 and 50 lum/W.

[i] All the specifications related to waveform and crest factor have been deleted from the first version:

- ***The lamp should resist a minimum of 5000 ON/OF cycles. Each cycle must consist on periods of 60 seconds ON and 150 seconds OFF, at the nominal voltage of the lamp. (C).***
- ***The lamp should resist a minimum of 10000 ON/OF cycles. Each cycle must consist on periods of 60 seconds ON and 150 seconds OFF, at the nominal voltage of the lamp. (R).***

Efficiency criteria often lead to recommendations for the exclusive use of fluorescent lamps. However, some experiences[16] suggest that lighting flexibility is greatly appreciated by users. Whilst high lighting levels are needed for cooking and reading (and can be obtained with fluorescent lamps), low lighting levels can be more appropriate for safety (avoiding snakes, etc.) and social gatherings. For example, a 2 W incandescent lamp delivers about 20 lumens and its colour rendering is very good, making it equivalent to a top class candle. This suggests:

- ***The simultaneous use of both fluorescent and low-power (< 2W) incandescent lamps should be allowed, as long as the total design load consumption is not exceeded. (R).***

Finally, the luminous efficiency can be greatly enhanced if some kind of light reflectors are added to the bulb mountings[17]. Reflectors are mounted above lamps to redirect the upward component of luminous flux downwards.

- *The waveform of the current through the fluorescent lamp must be symmetrical in time to within 10% (i.e., 60%/40% waveform maximum difference in symmetry) over the voltage range of 11 to 12.5 V at an ambient temperature of 25 °C. (**C**).*
- *The maximum crest factor (ratio of maximum peak to RMS voltage of the waveform applied to the fluorescent tube) should be less than 2 over the voltage range from 11 to 12.5 V at an ambient temperature of 25 °C. (**C**).*

Several of the experts who were consulted believed that the preceding set of requirements for ballasts and fluorescent lamps are not sufficient to ensure an acceptable technical quality. They recommend that the three last requirements should be stricter, as follows:

- *The DC component of the current through the fluorescent lamp should be zero. (**R**).*
- *The maximum crest factor (ratio of maximum peak to RMS voltage of the waveform applied to the fluorescent tube) should be less than 1.7 over the voltage range from 11 to 12.5 V at an ambient temperature of 25°C. (**R**).*
- *Means to preheat electrodes are recommended. (**R**).*

Reflectors with a high reflection factor can almost double the light output in some cases. Then:

- ***The luminous efficiency could be increased adding reflectors to the bulb mountings. (S).***

2.1.6. The wiring

Relatively low voltages and high currents are characteristics of SHSs, so even small voltage losses tend to be important, and can negatively affect

⇒ the current from PV generators (an increase in operating voltage moves the operating points towards the low-current region of the I-V curve of the PV generators),

⇒ battery charge regulation (differences between real battery voltages and voltage values at the charge regulator terminals)

⇒ the lifetime of fluorescent lamps (low voltage operation).

Special attention must therefore be paid to the reduction of voltage losses and, consequently, to wiring aspects. The following requirements are proposed:

- ***The sections of cables must cause less than 3% of voltage losses between PV modules and charge regulator, less than 1% between battery and charge regulator, and less than 5% between charge regulator and load. All of these apply at the maximum current condition. (R).***

It must be noted that voltage losses regulated by this specification are exclusively those associated with the wiring (cables and terminals). They should be interpreted as additional to the internal voltage drops at the charge regulator mentioned before.

For copper cables (specific resistance = 0.01724 $\Omega.\text{mm}^2/\text{m}$ at 20°C) and for 12 V nominal voltages, the following formula can be used:

$$S(\text{mm}^2) = 0.3 \times l(\text{m}) \times I_\text{M}(\text{A}) / \Delta V(\%)$$

where S is the minimum section of the cables, l the cable length, I_M the maximum current and ΔV the allowable voltage losses.

- ***Notwithstanding the above maximum voltage requirements, the minimum acceptable cross-section of***

the wire in each of the following sub-circuits is as follows: (C)

- ⇒ ***from PV module to charge regulator: 2.5 mm^2***
- ⇒ ***from charge regulator to battery: 4 mm^2***

For example, supposing the distance between PV module and charge regulator is equal to 10 m, and the maximum current is 5 A, the minimum cable section, *S*, should be greater than 0.3×10×5/3 = 5 mm^2

- ***External cables must be specifically adapted to outdoor exposure according to the international standard IEC 60811 or to the national standard for cables used by the relevant country. (C).***
- ***All cable terminals must allow for a secure and mechanically strong electrical connection. They must have low electrical resistance; leading to voltage losses less than 0,5% of the nominal voltage. This applies for each individual terminal at the maximum current condition (C)***
- ***Cable terminals should not be prone to corrosion arising from junctions or dissimilar metals. (C)***
- ***Cable that is ≥ 4 mm^2 must be fitted with copper terminals. Cable ends that are ≤ 2.5 mm^2 may be twisted and dipped in tin to secure a proper connection. (C).***
- ***All wiring shall be colour coded and/or labelled (R).***
- ***Fuses must be selected so that the maximum operating current will range from 50 to 80% of the rated capacity of the fuse. (C)***
- ***Fuses should preferably be installed in the positive line. (R).***
- ***Switches should be specifically adapted for DC. (R).***
- ***If AC switches are permitted, the nominal AC current rating should exceed the maximum DC current to be switched by at least 200%. (R).***
- ***Plug/socket combinations must be protected from reversing the polarity of the voltage supplied to the appliances. (C).***

When specific DC products are not available, it may be interesting to note that a practical way of implementing the requirement for protection against reverse polarity is to use conventional V_{AC} products of the type with two wires + an earth. In this case, the two main terminals can be short circuited and used as one of the poles (positive, for instance) while the earth terminal is used as the other pole (negative).

2.2 SAFETY

Concerning users' safety, SHSs offer the advantage of low voltage (typically 12 V) and the disadvantage of the existence of a battery, which has very high short-circuit power, contains sulphuric acid, and releases inflammable gases. To avoid the associated risks, it is appropriate to meet the following requirements:

- ***Both battery and charge regulator must be protected against over-currents and short-circuit currents by the placement of fuses, diodes, etc. in both PV generator and load lines. (C)***

Over-current and short-circuit protection can be practically implemented in several ways (fuses, diodes, etc.) and may or may not be built into the regulator box. In either case, such protection should be considered as a part of the charge regulator and the requirements concerning voltage drops that have been proposed in section 2.1.4, applied.

Battery accidents can result from tipping over the battery and its container –if used–, or by accidental placement of an electrical conductor, such as a screw driver or spanner, across the battery terminals.

Concerning the mounting and location of batteries, the following requirements apply:

- ***The battery must be located in a well ventilated space with restricted access. (C)***
- ***Provisions must be taken to avoid accidental short circuit of the battery terminals. (C)***

Both of these requirements can be met in several ways. Dedicated battery cases are being extensively used in Indonesia[18]**.** These have the advantages of being standardised products which are quick to install, but they add to the cost of SHSs, and may represent an intrusion into the house which users find difficult to accept. Special buildings for the battery and charge regulator, built by the PV users themselves with similar construction patterns to their houses, have been successfully employed in Bolivia[19]. These have the advantages of using local materials and of fostering the involvement of the users. Very good results have been achieved with such buildings, which can even resist the effects of direct lightning strikes, and the explosion of batteries or regulators, without damage to users.

To place the charge regulator in the battery housing can make it difficult for users to see the indicators on it. However, this inconvenience has been solved in a Brazilian project by building an outdoor battery housing against a wall of the house. This allows the charge regulator to be installed inside the house and still be kept very close to the battery, simply by passing the wires through the wall.

The installation of a complete lightning conductor system is far from being acceptable for economic reasons. For example, under the Bolivian High Plateau conditions, where lightning storms are frequent, the annual losses of PV modules and regulators due to lightning damage are about 0.2 %, while the cost of a lightning conductor system would represent an increase in the costs of a SHS of at least 35%. Moreover, other much cheaper protection possibilities exist, so:

- ***In regions with frequent storms, manual isolation of both the positive and negative poles should be installed on the PV side, so that the PV generator can be isolated when there is a risk of lightning strikes. (S)***

Finally, to avoid shock hazards when changing fluorescent lamps:

- ***Electrodes of ballasts must never be connected to lighting fixtures. (C)***

2.3 ENERGY PERFORMANCE

The energy performance of a SHS should be judged by the reliability of its electricity supply to the load, and the efficiency with which it uses the electricity from the PV generator. Both aspects are essentially related to system size, component efficiencies and consumers' use.

Reliability can be quantified in terms of *Loss of Load Probability*[20] (*LLP),* which is the probability of getting a blackout caused by a lack of solar radiation availability. Due to the random nature of solar radiation the value of *LLP* is always greater than zero, even if the PV system never breaks down. Obviously, for a given load, the bigger the PV system, the lower the *LLP* and the higher the reliability.

The *Performance Ratio*[21] *(PR)* quantifies how well the energy from the PV generator is used. It is defined as: “useful energy supplied to the load” divided by “the maximum theoretical energy which the PV generator can produce". This includes all of the losses occurring in the PV generator (cell temperature, mismatching, etc.), the losses from the rest of the system (self consumption of the charge regulator, battery efficiency, etc.) and also the available energy which is not consumed by the users. Obviously, a PV system which is "too big" can deliver much more energy than the users require, and this leads to energy waste and low *PR* values.

2.3.1. Energy requirements

"How much electricity has to be provided to a rural house in a developing country to be socially and economically acceptable?" Although this question is always at the origin of any PV rural electrification programme, its answer in terms of Wh/day, is far from being clear, even today[22]. Energy consumption data based on practical experience in developing countries are missing from the literature, which is paradoxical considering that thousands of PV systems are currently operating in Developing Countries. Instead, there are a great number of consumption scenarios where, although starting from very different hypotheses concerning the number of appliances and the length of time they are in use, the finally selected SHSs have an installed power in the range 40 - 50 Wp. This is because PV designers know that such systems are generally well accepted by the users, and the scenarios elaborated by them must therefore be interpreted as explanation exercises, rather than as designs for systems starting from an evaluation of actual needs.

The standardisation of energy needs (i.e. to fix a single value of energy consumption for a large number of different families) is an objective imposed by the technology itself, because it leads to standardised systems with reduced costs and guaranteed quality. However, it may not correspond so well with the needs of individual users, and PV history shows some interesting examples of this[23, 24].

However, to define a concrete "standard" energy consumption, in terms of Wh per day, is an unavoidable step for any PV rural electrification project, not only to meet the users' energy needs, but also to establish a technical reference for testing, for comparisons of different proposals, and for guarantees, etc.

The above mentioned approach to selecting SHSs in the range 40 - 50 Wp, is equivalent to requiring that :

- ***The design daily energy consumption value must be selected in the range 120 - 160 Wh day^{-1} (R).***

The selection of a single value within this range is clearly not without consequences. Obviously, the larger the selected value the more expensive the corresponding SHS, but also the greater the service offered to the users and, consequently, the greater the chances of success.

It is important to point out that this range should not be interpreted as giving an upper limit to the possibilities of using SHS, but rather as indicating the typical sizes of small systems which could provide basic services to a house with only lighting, radio and B/W television. Additional services such as fans, refrigerators, video, etc, can also be supplied with SHS providing that sufficient finance is available to pay for a larger PV generator and battery bank. In this case, specific energy consumption scenarios should be derived for each particular system.

2.3.2 Reliability and Sizing

The size of a PV- system is a general concept which involves the dimensions of the PV-array and the battery, and it is useful to define these dimensions relative to the load. On a daily basis, the *PV-generator capacity* (C_A), is defined as the ratio between the mean energy production of the PV array and the mean energy demand of the load (L). *The storage capacity*, C_S, is defined as the maximum energy that can be taken out from the battery divided by the mean energy demand of the load. So:

$$C_A = \eta \mathrm{A} G_d / L \qquad \text{and} \qquad C_S = C_U / L$$

where: A is the PV-generator area, η is the PV-generator efficiency, G_d is the mean daily irradiation on the PV generator, L is the mean daily energy consumption and C_U is the useful battery capacity, i.e., the product of the nominal battery capacity and the maximum depth of discharge allowed by the regulator. Note that the PV generator capacity C_A depends on the local meteorological conditions. This means that the same PV-array for the same load may be "large" in one place, while "small" in another one with lower solar radiation.

For any given location and load, two general ideas are intuitive: First, it is possible to find many different combinations of C_A and C_S leading to the same loss of load probability (*LLP)* value. Second, the larger is the PV-system size, the greater is the cost and the lower is the *LLP*.

The task of sizing a PV-system consists of finding the best trade-off between cost and reliability. Very often, the reliability is an a priori requirement from the user, and the problem for the PV-engineer is formulated as follows: “Which combination of C_A and C_S values leads to a given *LLP* value at the minimum cost?” To help with this task, it is useful to assume initially that the working voltage is always the nominal one, V_{NOM}, and that this in turn equals the maximum -power point voltage of the generator. Then:

$$L = V_{NOM}Q_M$$

$$\eta A = V_{NOM}I_{MG}/(1000\ \mathrm{W/m^2})$$

and

$$C_A = I_{MG}G_d/(Q_M F_S 1000\mathrm{W/m^2})$$

where: Q_M is the amount of charge (expressed in amp-hours) drawn daily by the load, I_{MG} is the PV generator maximum power current at Standard Test Conditions, and F_S is a safety factor which allows for the effects of dirt, the variation of PV efficiency with solar spectrum, etc. A typical value for F_S is 1.1. This approximation, in spite of appearing oversimplified, gives very good results, and its conditions for validity are discussed in section 2.3.3.

As mentioned above, a first possibility for sizing is to rely on guesswork, in which case, no quantitative relations are established between C_A, C_S and *LLP*. Instead, the sizes of the generator and the battery are simply obtained from rules of thumb based on previous experience. Widely used rules of thumb are:

- ***The size of the PV generator should be chosen to ensure that the energy produced during the worst month can, at least, equal the demand of the load (R).***
- ***The useful capacity of the battery (nominal capacity multiplied by the maximum depth of discharge) should allow for a three to five day period of autonomy (R).***

Note that the last specification merely repeats the stated in 2.1.3. One must mention that, as here presented, these specifications lead to a rather comfortable situation regarding energy availability. This is because the current from the PV generator is often greater than the maximum power current, and, because the factor $F_S = 1.1$ is quite generous. In practice, this typically leads to real generation/consumption ratios between 1.1 and 1.2, which ensure that the battery will not remain for extended periods without being fully charged.

For systems with manual PV array tracking, as mentioned in 2.1.2, most of the consulted experts think that energy lost through users forgetting to move the modules far outweighs the potential irradiation gains from manual tracking. For this reason :

- ***In cases where manual tracking is provided, the estimated surplus in collected irradiation should not be considered for sizing purposes. (R)***

The requirements concerning the size of the battery have already been explained in 2.1.3. Obviously, 5 days must be used where extended periods of low solar radiation are expected.

Reverting to the more formal analysis introduced above, this means that C_A=1 (with G_d corresponding to the lowest mean monthly radiation value over the plane of PV array) and $3<C_S<5$. This rule of thumb method is, of course, very simple and useful to obtain a first idea of the dimensions of the required SHS. However, it has some disadvantages. It does not allow the system reliability to be quantified or optimised and, especially annoying for rural electrification purposes, it does not allow the consideration of different SHS variants (for example, adapting the size of the PV generator to available PV module sizes and compensating for this by choosing smaller or larger batteries). More advanced sizing methods, dealing with all these matters, are available in the literature[25, 26, 27], though they are still not being extensively used.

2.3.3 Energy efficiency

An ideal PV system operating with its modules at 25°C throughout the day would have a *PR* of 100%, and the reasons why real operating values will be lower than this (typically about 60%) are:

⇒ Array losses (shadowing, cell temperature higher than 25°C, mismatch, losses in cables, operating voltage different from that corresponding to the maximum power point)

⇒ System losses (charge regulators, batteries, and cables)

⇒ Poor use of the available energy

Array losses are minimised by careful installation (module ventilation and suitable cable sizes) and by using PV modules whose electrical characteristics are well adapted to the task of charging batteries in the particular climate concerned. System losses are minimised by using low consumption regulators and good quality batteries. The following requirements are therefore proposed:

- ***The PV generator must be entirely free of shadows during, at least, 8 hours per day, centred at noon, all through the year. (C)***
- ***With an irradiance of 800 W/m^2, the maximum power voltage of the PV generator at the annual maximum***

ambient temperature of the site $V_{MAX}(T_{MAX})$ should lie between 14.5 and 15 V. (R).

This requirement ensures that the current from the PV generator is greater than the maximum power current for most of the time, provided that the requirements concerning voltage drops in the wires and charge regulator are also met. It can be shown that below this voltage range, there is a risk of a reduced battery charge, whereas above this range the number of solar cells is unnecessarily large. If more accurate information is not available, then the following approximate formula can be used:

$$V_{\mathrm{MAX}}(T_{\mathrm{MAX}}) = V_{\mathrm{MAX\ (STC)}} - 2T_{\mathrm{MAX}}N_{\mathrm{CS}}$$

where $V_{\mathrm{MAX(STC)}}$ is the maximum power voltage under Standard Test Conditions, N_{CS} is the number of solar cells in series, T_{MAX} is the annual maximum ambient temperature of the site in $^{\circ}$C, and all voltage values are given in mV.

It should be mentioned that specifications issued by the World Bank sometimes impose the exclusive use of PV modules with no less than 36 series-connected solar cells. However, this appears to be rather a conservative approach. In fact, PV modules with 32 and 33 solar cells are being used in many places without problems, providing the voltage losses in the charge regulator and wiring are kept low. Hence,

- ***The parasitic electrical consumption of the charge regulator in normal operation (i.e., PV generator and load lines "on" and push-button (if existing) not pressed) must not exceed the 3% of the foreseen daily consumption[j]. (C).***

This requirement for the parasitic electrical consumption of the regulator is generally accepted. However, existing technology allows for still less charge regulator consumption, so it is also possible to consider:

- ***The parasitic electrical consumption of the charge regulator in normal operation (i.e., PV generator and load lines "on" and push-button (if existing) not pressed) should not exceed the 1% of the foreseen daily consumption[k]. (R).***

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[j] This specification substitutes the one in the first version, in which: "*The parasitic electrical consumption of the charge regulator in normal operation (i.e., PV generator and load lines "on" and push-button (if existing) not pressed) must not exceed 15 mA. (C)*. Even if the application the regulator is devoted to were unknown, this specification sill be verified in the tests.

[k] This specification substitutes the one in the first version, in which: "*The parasitic electrical consumption of the charge regulator in normal operation (i.e., PV generator and load lines "on" and push-button (if existing)*

2.4 USER FRIENDLINESS

SHSs are rather simple. Generally, their users do not face significant difficulties to learn the right way to use them, once they properly understand the intrinsic limitation of energy availability. Information displayed by the charge regulator can also help with this.

Regulators which display information on electrical parameters (charging current, battery voltage, etc.) have been extensively used in the past. Nowadays, however, it is widely accepted that this is not very useful. When the supply is cut off, the most important information for users is to know whether this was due to equipment failures or to exhaustion of energy availability. Further, in order that users can adopt energy saving procedures in advance, it is also useful to indicate the level of risk that the battery will soon be disconnected from the load due to low energy availability. For this, a simple two or three level display can be mounted on the charge regulator to show the state of charge of the battery. It is therefore proposed that the following approach be adopted :

- ***If the load can be used without any restriction, then the battery state of charge is indicated by a green signal (C).***
- ***If the battery has been disconnected from the load because its state of charge is too low, then this is indicated by a red signal (C).***
- ***If there is a risk that the battery will soon be disconnected from the load, then this is indicated by a yellow signal (R).***

Obviously, red and yellow signals correspond to the “load disconnection” and “warning” voltages discussed in 2.1.4. It is also helpful to display other more user-friendly indication signals. For example: *happy*, *sad* and *intermediate* faces.

All these signals can be permanently activated providing that very low energy consumption LEDs are used. However, a better solution is to activate them only when a push-button is pressed. This not only saves energy, but also fosters the active participation of the users in the functioning of their SHS. Because of this

- ***Manual activation of the state of charge display signals may be provided (S).***

---

not pressed) must not exceed 5 mA. (**R**). Even if the application the regulator is devoted to were unknown, this specification sill be verified in the tests.

Obviously, easy reading of the state-of-charge display is only possible if the charge regulator is located in an easily accessible place, and in a frequently used room. However, in some cases, this may conflict with the earlier recommendation to place the charge regulator as close as possible to the battery, which itself must be located in a well ventilated location with restricted access. In such cases, a good solution for the regulator is to disconnect the load when the state-of-charge reaches the risk level, and to provide a manual reset for such disconnections. In this way, the users are made aware of the risk of disconnection without having to keep looking at the state of charge display. For this approach:

- ***The user may be warned that the battery state of charge has fallen to the "risk" level, by an automatic disconnection of the battery from the load, which can be manually re-set (S).***

It is worth mentioning that many existing regulators provide additional information, which is mainly of use to maintenance personnel. Experience suggests that most users should not have to carry out any task other than cleaning the PV modules. There are worrying examples of what can happen when other maintenance tasks are left to the users[28]. Each rural community, or similar, should have a person who is responsible for primary maintenance (failure diagnostics, replacing fuses, modifying the wiring, etc.), and they must be previously trained. Any additional information from regulators should be addressed to them, and therefore adapted to their skills and role in the maintenance scheme.

2.5 INSTALLATION AND MAINTENANCE

SHSs should preferably be understood as turn-key systems, which are fully installed and operating before being handed over to their users. However, tenders can also be issued on a "materials only" basis by system integrators (ESCOs, etc). In this case, particular attention should be paid to ensuring that all the materials needed for installation, such as screws, battery connectors, etc., are included and correctly identified. Hence:

- ***All the necessary installation materials (screws, connectors, fittings, etc.) must be included into the SHS supply. (C)***
- ***PV modules, batteries, charge regulators and ballasts must be properly labelled (C)***

SHS maintenance tasks which can be carried out directly on site are: cleaning of PV modules, modifying the wiring, topping up of battery water levels, and the substitution of fuses, lamps and charge regulators. To help with this, and also to simplify initial installation of the SHS, it is appropriate to require that:

- ***Support structures must be mounted to allow easy access for PV module cleaning and connection boxes inspection (*****C*****)***
- ***Support structures must be mounted such that their resistance to corrosion, fatigue and wind are preserved (*****C*****)***
- ***Pedestal and wall mountings are preferable to roof mountings for PV generators. (*****S*****).***

Pedestal and wall mountings normally allow easy access to the PV modules without risking the water tightness of the roof, and can provide an additional degree of freedom when seeking an unshadowed location for the PV generator. Roof mountings can sometimes lead to cost savings and, hence, can also be accepted providing that there is space between the roof and the modules for cooling air to circulate. So:

- ***If roof mounting is permitted, then a gap of at least 5 cm must be provided between the PV modules and the roof for the circulation of cooling air. (*****C*****)***
- ***If roof mounting is permitted, support structures should not be fixed onto roofing sheets, but to a roof beam or an integral part of the structure of the house (*****C*****)***
- ***The battery should be placed in an easily accessible location (Note: access should normally be restricted, for example by means of a locked door) (*****R*****).***

"Easily accessible" means that cleaning of the battery terminals, checking the level of electrolyte, topping up the water levels and replacing fuses (if existing) can be easily done without moving the battery.

- ***Charge regulators and lamps must be provided with suitable mounting brackets / fixings (installation must be relatively simple) (*****C*****).***
- ***Charge regulators and lamps must be designed in such a way that access to fuses and wiring terminals is relatively easy (*****C*****).***

- ***Lamp lenses, covers grids, etc. (if used) must be insect proof. (C).***
- ***Lamp lenses, covers grids, etc. (if used) must be easily removable by the users for bulb replacement or for cleaning. (R).***
- ***All fluorescent tubes must be available locally. (C).***
- ***Tooling requirements must be minimised (avoid different bolt / screw sizes, etc.) (C).***

Finally, all the wiring should be installed in compliance with the state of the art. In particular

- ***Cables must be secured to support structures or walls to fully avoid mechanical forces on other elements (connection boxes, ballasts, switches, etc) (C).***
- ***Cables must be stapled into the wall at appropriate intervals to secure them both horizontally and vertically if exposed, otherwise they should be buried or recessed and plastered into walls. (C).***
- ***Cables must be kept out of reach of small children. (R).***
- ***In general, all cable lays must be horizontal or vertical, never oblique. (R).***

2.6 FLEXIBILITY

On the assumption that all the above mentioned requirements are fulfilled, it is also important that a SHS would be designed in a flexible way such that any component can be substituted by a similar component from another supplier or by a technically improved component from the same supplier. Flexibility in terms of system sizing is also important. For this, special attention needs to be paid to the possibility of enlarging a SHS by increasing the size of its PV generator or its battery. The compatibility of the battery and regulator is also a key issue.

PV modules of identical nominal voltage can be connected in parallel without any restriction, so when PV generators are enlarged it is only necessary to check wiring sizes and the ability of the regulator to manage the increased value of the maximum current.

To enlarge the storage capacity of a SHS it is necessary to replace the complete former battery with a new one, because parallel connections of old and new batteries are never satisfactory. It should be mentioned that specifications from the World Bank typically allow up to two identical batteries to be connected in parallel, though they also indicate that only one is preferable, and some battery manufacturers agree with this opinion. Hence, the following points need to be stressed :

- ***Parallel connections of more than two batteries are not permitted (C).***
- ***Parallel connections of different batteries are not permitted(C).***
- ***Parallel connections of old and new batteries are not permitted (C).***

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3. SHS STANDARD

3.1 SCOPE

This section presents a proposition for a Universal Standard for SHSs, which are designed to provide the user with a convenient means of supplying power for small electric loads; mainly lights, radio/cassette and black and white B/W television.

This standard applies to the technical characteristics of the SHS itself, i.e., the PV generator, the battery, the charge regulator and the wiring, and also to the technical characteristics of the lights. However, it does not apply to any other electric loads.

This standard applies exclusively to SHS using 12 V_{DC} and lead acid batteries.

The requirements specified in this Standard are classified according to their level of applicability: system, components and installation, and to their importance : *compulsory*, *recommended* or *suggested*. Each requirement has a key label composed of two letters and one number (eg: CB6). The first letter indicates the importance of the requirement (i.e. compulsory), and the second letter indicates the level of applicability or the component (i.e. battery) as shown in the Table below. The number is just an identifier for reference purposes.

First letter	Second letter
Compulsory **R**ecommended **S**uggested	**S**ystem PV **G**enerator S**U**pport structure **B**attery Charge **R**egulator **W**iring **L**amps **I**nstallation

3.2 DEFINITIONS

C_A	*PV* Generator capacity
C_B	20-hours nominal battery capacity (amp-hour).
C_U	Useful battery capacity
DOA	Days of Autonomy in a SHS

$G_{\mathrm{d}}(0)$	Monthly mean of global daily irradiation on a horizontal surface
$G_{\mathrm{d}}(\beta)$	Monthly mean of global daily irradiation on a plane tilted at angle β and oriented towards the equator
I_{MG}	Maximum-power point current of the PV generator at Standard Test Conditions.(1000 W/m^2 of irradiance and 25 °C of solar cell temperature)
LLP	Loss of load probability
$NOC(50\%)$	Cycle life of the battery (Number of Cycles) when discharged to a depth of discharge of 50%
PD_{MAX}	Maximum depth of discharge of the battery.
Q_{M}	Daily current consumption
T_{MAX}	Maximum ambient temperature
F_{S}	Safety factor

3.3 GENERAL INFORMATION

Climatic conditions can affect the performance and durability of SHS. If no particular conditions are proposed, then the following should be used:

- Humidity: 80 %
- Ambient Temperature range: -5°C to 40°C
- Maximum wind speed: 120 km/h

3.4 DESIGN INFORMATION

References for system configuration are:

Number x Power (W) of fluorescent lamps

Number x Power (W) of incandescent lamps

Number x Power of outlets (W)

Data for design purposes are:

Daily consumption of current Q_{M} = _______ Ah/day

Tilt angle of PV array β*SYMBOL* = _______

Irradiation on PV array $G_{\mathrm{d}}(\beta)$ = _______ kWh/m^2

Max ambient temperature T_{MAX} = _______ °C

3.5 SYSTEM REQUIREMENTS

3.5.1 Compulsory

CS1 Both battery and charge regulator must be protected against over-currents and short-circuit current by the placement of fuses, diodes, etc. in both PV generator and load lines.

CS2 PV modules, batteries, charge regulators and ballasts must be properly labelled.

3.5.2 Recommended

RS1 The design daily energy consumption value must be selected in the range 120 - 160 Wh day^{-1}.

RS2 The size of the PV generator should be chosen to ensure that the energy produced during the worst month can, at least, equal the demand of the load.

RS3 The useful capacity of the battery (nominal capacity multiplied by the maximum depth of discharge) should allow for a three to five day period of autonomy.

RS4 In cases where manual tracking is provided, the estimated surplus in collected irradiation should not be considered for sizing purposes.

RS5 With an irradiance of 800 W/m^2, the maximum power voltage of the PV generator at the annual maximum ambient temperature of the site V_{MAX} (T_{MAX}) should lie between 14.5 and 15 V.

3.5.3 Suggested

SS1 In regions with frequent storms, manual isolation of both the positive and negative poles must be installed on the PV side, so that the PV generator can be isolated when there is a risk of lightning strikes.

3.6 PV GENERATOR REQUIREMENTS

3.6.1 Compulsory

None

3.6.2 Recommended

RG1 PV modules certified according to the international standard IEC-61215 or to the national standard of PV modules used by the relevant country.

3.6.3 Suggested

None

3.7 SUPPORT STRUCTURE REQUIREMENTS

3.7.1 Compulsory

CU1 Support structures should be able to resist, at least, 10 years of outdoor exposure without appreciable corrosion or fatigue.

CU2 In the case of framed PV modules, only stainless steel fasteners (screws, nuts, rings, etc.) may be used for attaching them to support.

CU3 In the case where manual tracking (2 or 3 positions per day, moving from East to West) is used, all of its features must meet the support structure requirements specified here.

3.7.2 Recommended

RU1 Support structures must withstand winds of 120 km/h.

RU2 Tilt angle should be selected to optimise the energy collection during the worst month, i.e., the month with the lowest ratio of monthly mean daily irradiation to the monthly mean daily load. Generally, the following formula can be used

$$\text{Tilt}(^{\circ}) = \max \{ |\Phi| + 10^{\circ}; 10^{\circ} \}$$

where Φ is the latitude of the installation.

RU3 Static support structures are generally preferable to tracking-ones.

3.7.3 Suggested

SU1 Pedestal and wall mountings are preferable to roof mountings for PV generators.

3.8 BATTERY REQUIREMENTS

3.8.1 Compulsory

CB1 The thickness of each plate must exceed 2mm.

CB2 The amount of electrolyte must exceed 1.15 l per 100 Ah of 20-hour nominal capacity and per cell.

CB3 The 20-hour nominal battery capacity in amp-hours (measured at 20 ^{o}C and until a voltage of 1.8 V/cell) should not exceed CR times the PV generator short-circuit current in amps (measured at Standard Test Conditions). For each type of battery, CR values are proposed in the table below:

Battery type	***CR***	
	Compulsory	**Recommended**
Tubular	20	15
SLI:		
- Classical	40	30
- Modified	40	35
- Low-maintenance	40	30

CB4 The maximum depth of discharge, PD_{MAX}, (referred to the 20-hours nominal battery capacity) should not exceed the values proposed in the table below:

Battery type	**PD_{MAX}**	
	Compulsory	**Recommended**
Tubular	80	70
SLI		
- Classical	50	30
- Modified	60	40
- Low-maintenance	30	20

CB5 Provision must be made to ensure that the capacity of the delivered batteries is not below the 5% of the nominal value.

CB6 The self-discharge rate of batteries, at 25°C, must not exceed 6% of their rated capacity per month.

3.8.2 Recommended

RB1 The separator must be made of microporous polythene.

RB2 The useful capacity of the battery, C_U, (20 hours nominal capacity, as define above, multiplied by the maximum depth of discharge) should allow for a three to five day period of autonomy.

RB3 The cycle life of the battery (i.e., before its residual capacity drops below 80% of its nominal capacity) at 20°C, must exceed a certain number of cycles, NOC, when discharged down to a depth of discharge of 50%. For each type of battery, a NOC value is given in the table below:

Battery type	NOC
Tubular	600
SLI	
- Classical	200
- Modified	200
- Low-maintenance	300

3.8.3 Suggested

SB1 The density of electrolyte must not exceed 1.25 g/cl.

3.9 CHARGE REGULATOR REQUIREMENTS

3.9.1 Compulsory

CR1 Deep discharge protection must be included.

CR2 “Load-disconnection” voltages should correspond to the maximum depth of discharge values defined in CB4, when the discharge current, in amps, is equal to the daily load consumption, in amp-hours, divided by 5.

CR3 “Load-disconnection”, “load-reconnection” and “warning” voltages should be accurate to within ±1% (±20 mV/cell, or ±120 mV/battery of 12 V) and remain constant over the full range of possible ambient temperatures.

CR4 End-of-charge voltage should lie in the range from 2.3 to 2.4 V/cell (at 25 °C).

CR5 In the case of two-step controllers, the reposition voltage should lie in the range from 2.15 to 2.2 V/cell, at 25°C.

CR6 A temperature correction of -4 to -5 mV/°C/cell should be applied to the end-of-charge and reposition voltage ranges mentioned above. (This specification must be **C** only if ambient [indoor] temperatures around the controller are expected to vary significantly during the year, say by more than ±10°C. Otherwise, temperature compensation circuitry is not really needed).

CR7 End-of-charge and reposition voltages should be accurate to within 1% (i.e. ±20mV/cell, or ±120mV per 12 V battery).

CR8 If electro-mechanical relays are used, the reposition of the charge should be delayed for between 1 and 5 minutes.

CR9 All the charge regulator terminals should easily accommodate, at least, 4 mm^2 section cables.

CR10 Internal voltage drops between the battery and generator terminals of the charge regulator must be less than 4% of the nominal voltage (≅0.5 V for 12 V) in the worst operating conditions, i.e., with all the loads “off” and the maximum current from the PV generator.

CR11 Internal voltage drops between the battery and load terminals of the charge regulator must be less than 4% of the nominal voltage (≅0.5 V for 12 V) in the worst operating condition, i.e., with all the loads “on” and no current from the PV generator.

CR12 Controlled overcharging of “low-maintenance” SLI batteries must be avoided.

CR13 Reverse current leakage protection must be provided.

CR14 The charge regulator must be able to resist any possible "non-battery" operating condition, when with the PV generator is operating at Standard Test Conditions and with any allowed load.

CR15 The charge regulator must also protect the load in any possible "non-battery" condition, as defined above, by limiting the output voltage to a maximum of 1.3 times the nominal value. (Full interruption of output voltage is also allowed).

CR16 The charge regulator must resist without damage the operating condition defined by: ambient temperature of 45°C, charging current 25% greater than the short circuit current of the PV generator at Standard Test Conditions, and discharging current 25% greater than that corresponding to the full load "on" at the nominal operating voltage.

CR17 Charge regulator boxes must provide protection to at least IP 32, according to IEC 529 or DIN 40050.

CR18 The charge regulator must not produce radio frequency interference in any operation conditions.

CR19 The parasitic electrical consumption of the charge regulator in normal operation (i.e., PV generator and load lines "on" and push-button (if existing) not pressed) must not exceed 15 mA.

CR20 If the load can be used without any restriction, then the battery state of charge is indicated by a green signal

CR21 If the battery has been disconnected from the load because its state of charge is too low, then this is indicated by a red signal

3.9.2 Recommended

RR1 "Load-reconnection" voltage should be 0.08 V/cell (or 0,5 V per 12 V) higher than the "load-disconnection" voltage.

RR2 Warning facilities must be included.

RR3 "Warning" voltage should be selected such that the warning signal is activated 30 minutes before "load disconnect" occurs, assuming all the loads are "on".

RR4 Disconnection of the load should be delayed for between 3 and 30 seconds after the load disconnection voltage has been reached.

RR5 End-of-charge voltage should correspond to a recharge factor between 0,95 and 1, at a constant current equal to the short-circuit current of the PV generator at the STC.

RR6 The charge regulator should allow battery charging from the PV module for any voltage greater than 1.5 V/cell.

RR7 Charge regulator boxes should provide protection to IP 54, according to IEC 529 or DIN 40050.

RR8 The charge regulator should be protected against reversed polarity in both PV generator and battery lines. Diode-fuse or other arrangements can be used.

RR9 The charge regulator should be protected against induced over-voltages by means of a 1000 W, or greater, transient voltage suppressor inserted between both (+ and -) poles, at the PV generator input.

RR10 The charge regulator should be protected against induced over-voltages by means of a 1000 W, or greater, transient voltage suppressor inserted between both (+ and -) poles, at the load output.

RR11 The parasitic electrical consumption of the charge regulator in normal operation (i.e., PV generator and load lines "on" and push-button (if existing) not pressed) must not exceed 5 mA.

RR12 If there is a risk that the battery will soon be disconnected from the load, then this is indicated by a yellow signal

3.9.3 Suggested

SR1 The charge regulator can include an independent battery voltage sensor line.

SR2 Controlled overcharging should be done at a constant voltage of 2.5 V/cell. Overcharging should occur after each deep-discharge and/or at 14-day intervals. Overcharging should last between 1 and 5 hours.

SR3 It should be possible for controlled overcharging to be manually switched off.

SR4 The upper and lower controlled overcharge voltages should, respectively be 2.5 and 2.25 V/cell.

SR5 Manual release of the deep-discharge protection is not permitted.

SR6 Manual activation of the state of charge display signals may be provided

SR7 The user may be warned that the battery state of charge has fallen to the "risk" level, by an automatic disconnection of the battery from the load, which can be manually re-set

3.10 LAMPS REQUIREMENTS

3.10.1 Compulsory

CL1 Ballasts must ensure safe and regulated ignition in the voltage range from –15% to +25% of the nominal voltage (10.3 V to 15 V for 12 V battery).

CL2 Ballasts must be protected against destruction when:

- the lamp is removed during operation or the ballasts are operated without the lamp.
- the lamp does not ignite.
- the supply voltage is reverse-poled.
- the outputs of the electronic ballast are short circuited.

CL3 Ballasts must not produce radio frequency interference.

CL4 Minimum luminous flux for the total ballast and fluorescent lamp system must be 80% of the nominal value.

CL5 Minimum electrical efficiency of the ballasts must be 70% in all the range of the operating voltage (–15% to +25% of the nominal voltage).

CL6 Luminous yield for the total ballast and fluorescent lamp system must be at least 25 lum/W.

CL7 The waveform of the current through the fluorescent lamp must be symmetrical in time to within 10% (i.e., 60% / 40% waveform maximum difference in symmetry) over the voltage range of 11 to 12.5 V at an ambient temperature of 25°C.

CL8 The maximum crest factor (ratio of maximum peak to RMS voltage of the waveform applied to the fluorescent tube) should be less than 2 over the voltage range from 11 to 12.5 V at an ambient temperature of 25°C.

CL9 Electrodes of ballasts must never be connected to lighting fixtures.

CL10 Lamp lenses, covers grids, etc. (if used) must be insect proof.

CL11 All fluorescent tubes must be of a widely available type.

3.10.2 Recommended

RL1 The consumption of ballasts when they are operated without lamps must be lower than 20% of their nominal power.

RL2 Luminous yield for the total ballast and fluorescent lamp system must be at least 35 lum/W.

RL3 The DC component of the current through the fluorescent lamp should be zero.

RL4 The maximum crest factor (ratio of maximum peak to RMS voltage of the waveform applied to the fluorescent tube) should be less than 1.7 over the voltage range from 11 to 12.5 V at an ambient temperature of 25^{o}C.

RL5 Means to preheat electrodes are recommended.

RL6 The simultaneous use of both fluorescent and low-power (< 2W) incandescent lamps should be allowed, as long as the total design power is not exceeded.

3.10.3 Suggested

SL1 The luminous efficiency could be increased adding reflectors to the bulb mountings.

SL2 Luminous yield for the total ballast and fluorescent lamp system must be at least 50 lum/W.

3.11 WIRING REQUIREMENTS

3.11.1 Compulsory

CW1 Notwithstanding the above maximum voltage requirements, the minimum acceptable cross-section of the wire in each of the following sub-circuits is as follows:

- from PV module to charge regulator: 2.5 mm^2
- from charge regulator to battery: 4 mm^2

SL3 External cables must be specifically adapted to outdoor exposure according to the international standard IEC 60811 or to the national standard for cables used by the relevant country.

SL4 All cable terminals must allow for a secure and mechanically strong electrical connection. They must have low electrical resistance; leading to voltage losses less than 0,5% of the nominal voltage. This applies for each individual terminal at the maximum current condition.

SL5 Cable terminals should not be prone to corrosion arising from junctions or dissimilar metals.

SL6 Cable that is $\geq$ 4 mm^2 must be fitted with copper terminals. Cable ends that are $\leq$ 2.5 mm^2 may be twisted and dipped in tin to secure a proper connection.

SL7 Fuses must be selected so that the maximum operating current will range from 50 to 80% of the rated capacity of the fuse.

SL8 Plug/socket combinations must be protected from reversing the polarity of the voltage supplied to the appliances.

3.11.2 Recommended

RW1 All wiring should be colour coded and/or labelled.

RW2 Fuses should be prefereably installed in the positive line.

RW3 Switches should be specifically adapted for DC.

RW4 If AC switches are permitted, the nominal AC current rating should exceed the maximum DC current to be switched by at least 200%.

3.11.3 Suggested

None

3.12 INSTALLATION REQUIREMENTS

3.12.1 Compulsory

CI1 The battery must be located in a well ventilated space with restricted access.

CI2 Provisions must be taken to avoid accidental short circuit of the battery terminals.

CI3 The PV generator must be entirely free of shadows during, at least, 8 hours per day, centred at noon, all through the year.

CI4 All the necessary installation materials (screws, connectors, fittings, etc.) must be included into the SHS supply.

CI5 Support structures must be mounted to allow easy access for PV module cleaning and connection boxes inspection.

CI6 Support structures must be mounted such that their resistance to corrosion, fatigue and wind are preserved.

CI7 If roof mounting is permitted, then a gap of at least 5 cm must be provided between the PV modules and the roof for the circulation of cooling air.

CI8 If roof mounting is permitted, support structures should not be fixed onto roofing sheets, but to a roof beam or an integral part of the structure of the house.

CI9 Charge regulators and lamps must be provided with suitable mounting brackets / fixings (installation must be relatively simple).

CI10 Charge regulators and lamps must be designed in such a way that access to fuses and wiring terminals is relatively easy.

CI11 Tooling requirements must be minimised (avoid different bolt / screw sizes, etc.)

CI12 Cables must be stapled into the wall at appropriate intervals to secure them both horizontally and vertically if exposed, otherwise they must be buried or recessed and plastered into walls.

CI13 Cables must be secured to support structures or walls to fully avoid mechanical forces on other elements (connection boxes, ballasts, switches, etc)

CI14 Parallel connections of more than two batteries are not permitted

CI15 Parallel connections of different batteries are not permitted.

CI16 Parallel connections of old and new batteries are not permitted.

3.12.2 Recommended

RI1 The battery should be placed in an easily accessible location (Note: access should normally be restricted, for example by means of a locked door).

RI2 Cables should be kept out of reach of small children.

RI3 All cable lays should be horizontal or vertical, never oblique

3.12.3 Suggested

None

ANNEX 1. LIST OF COMPILED STANDARDS

COUNTRY	**INSTITUTION**	**TITLE**	***YEAR***
Bolivia	*PROPER*	*Especificaciones técnicas*	*1996*
Brazil	*Centro de Pesquisas de Energia Electrica*	*Manual de Engenharia. Sistemas Fotovoltaicos*	*1995*
France	*Electricité de France*	*Directives générales pour l'utilisation des énergies renouvelables dans l'électrification rurale décentralisée*	*1997*
Germany	*GTZ*	*Basic Electrification for Rural Households*	*1995*
Germany	*Fraunhofer-Institut für Solare Energiesysteme*	*Anforderungskatalog für Laderegler der Leistungsklasse von 50 W bis 200 W bei 12V/24V Nennspannung*	*1996*
India	*Indian Renewable Energy Development Agency*	*Model of Technical Specification for Solar Home Lighting Systems*	*1997*
Indonesia	*BPP Technology*	*Specifications for Solar Home Systems*	*1996*
Kenya	*Energy Alternatives AFRICA*	*Draft Components and Installation Standards*	*1997*
Mexico	*Instituto de Investigaciones Eléctricas*	*Especificación técnica para sistemas fotovoltaicos de iluminación doméstica*	*1992*
Sahel	*CILSS*	*Programme Regional d'Utilisation de l'Energie Solaire Photovoltaique dans les pays du Sahel. CR-VI FED. Appel d'Offres Restreint*	*1989*
South Africa	*ESKOM Non-Grid Electrification*	*Standard Technical Specification for the supply of PV Systems Equipment for Solar Homes*	*1997*
Spain	*Instituto de Energía Solar*	*Elaboration of a label "Adapted PV Equipment for Developing Countries". Power for the World - A Common Concept. EC-JOU-CT93 - 0421*	*1994*
Spain	*CIEMAT*	*Estándares de calidad para los "Solar Home Systems (SHS)" en Sudáfrica*	*1997*
Sri Lanka	*Solar Power & Light Co. Ltd.*	*Specifications for Solar Home Systems*	*1997*
Tunisia	*Agence pour la maitrise de l'Energie*	*Cahier de charges: Acquisition et installation de 2000 petits systemes photovoltaiques*	*1995*
USA	*Asia Alternative Energy Unit (ASTAE)*	*Best Practices for Photovoltaic Household Electrification Programs*	*1996*
USA	*Sandia National Lab*	*Stand-Alone Photovoltaic Systems – A Handbook of Recommended Design Practices*	*1991*
Zaire	*Fonds National Medico-Social*	*Cahier des Charges pour Fourniture, Installation et Maintenance des Equipements*	*1991*

ANNEX 2

List of reviewers

Name	Organisation	Country
M.A. Abella	Instituto de Energías Renovables, C.I.E.M.A.T.	Spain
E. Alcor	ATERSA	Spain
S. Bezudenhaut	ESKOM	South Africa
W. Canedo	PROPER	Bolivia
L. Gunaratne	Solar Power & Light Co, Ltd	Sri Lanka
T. Hart	IT Power India	India
M. Hankins	Energy Africa	Kenya
J. Huacuz	Instituto de Investigaciones Eléctricas	Mexico
R. Posorski	GTZ	Germany
Klaus Preisser	Fraunhofer-ISE	Germany
Anhua Wang	Director UNDP Project for Development, PV in Western China. President of GANSU-PV Cy Ltd.	China
R. Zilles	Instituto de Electrotécnica e Energia. Universidade de Sao Paulo	Brazil