GUIDELINES
FOR
SOLAR PHOTOVOLTAIC SYSTEMS FOR AIDS TO NAVIGATION

DECEMBER 2001
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TABLE OF CONTENTS

1 INTRODUCTION

A large number of services involved in marine aids to navigation (AtoN) are increasingly familiar with solar energy systems, and know that Photo Voltaic (PV) energy is an excellent technical and economic choice for powering many AtoN.

In order to have the best results with PV energy, it is of prime importance to size, to install, to operate, and to maintain the solar PV system correctly. This document can be used as an introduction to the application of PV energy systems to AtoN. It should be read in conjunction with other IALA publications that are listed in the reference section.

Readers should also bear in mind that PV systems continue to develop, and so they should endeavour to keep abreast of the latest technology.

Included at the end of this document are summaries of the replies from a wide range of countries to questionnaires circulated to IALA members in 2000, on the subjects of energy sources.

2 GENERAL CONSIDERATIONS

An AtoN PV power system in its simplest form consists of a solar panel and a secondary battery. A charge regulator may also be used. PV power systems are a well-proven technology and equipment is available from many suppliers. When properly designed, PV power systems are very reliable and are the most widely used renewable energy source for charging secondary batteries.

If reliable mains power is economically available, it is usually the preferred energy source. Wave and wind energy equipment generally have higher capital cost and require more maintenance Photo Voltaic systems because of moving parts.

The best places to use solar power are
- Where there is high insolation,
- For a low or medium power load,
- At fixed installations.

Solar power cannot be used where:
- No direct sunlight is available,
- Space is limited, for example on small buoys,
- Ventilation for secondary battery is not available,
- Bird fouling is excessive, and,
- The electrical load is too high.

2.1 Conversion of existing lights to PV energy

There has been a trend in some countries to reduce the range of long-range visual AtoN, and this combined with the use modern high efficiency light sources may mean that the AtoN can be converted to PV energy.

2.2 PV module technology

The most commonly used technologies are single crystalline or multi-crystalline silicon solar cells encapsulated with glass in front and glass, resin, or metal on the back. Amorphous silicon PV modules are not yet efficient enough to be used with AtoN.

2.3 Modular design considerations

If the installation consists of a single aid to navigation, it is usually matched to a single power unit, which comprises one or more solar PV modules, a battery and [usually] a charge regulator.

If the installation consists of more than one aid, or a combination of aids and control systems, the choice lies between having separate power systems for each system load or a solar PV power system that feeds a common supply bus bar.

The use of a separate power system for each aid has the advantage that if the power to one aid fails, the other aids will continue to operate normally, but such a system will be more expensive in first cost, and will require a little more time for maintenance visits. The common supply power system may have advantages in allowing a closer match between the power system and the total station load, but would require protection against over-consumption or short circuits in any of the loads. If the equipment that is used at the station requires several operating voltages, this may dictate the number of power systems to be installed. The final choice of system configuration lies in a careful evaluation of the advantages and disadvantages of the possible configurations.

2.3.1 Example of a modular design concept

The Australian Maritime Safety Authority has implemented the following concept: Use of a standardised solar PV powered generator (module + battery + charge regulator) that is installed in multiples to reach the power needed or to increase the reliability.

2.4 Backup energy sources

A cost comparison between [a] over sizing the PV generator and [b] adding a back-up energy source should be made, taking into account the fact that generally back up sources are less reliable than solar PV generators. However with large PV generators (> 1000 Wp) and latitudes above 40° where summer and winter solar irradiation levels are quite different, a back-up source can be considered for the purpose of reducing the system battery capacity, and in so doing, saving weight, equipment volume and building space.

3 CALCULATING THE TOTAL ELECTRICAL LOAD

When planning to power an existing or a new AtoN, choice of the lowest consumption equipment to meet the requirements for range and character is highly advisable. Matters to consider are power consumption and efficiency of the light source, optic equipment, power consumption of the control system and of the control and monitoring equipment.

3.1 Load operating times

The first task in establishing the total electrical load is to estimate the length of time that each load will be operating. Estimating the length of time that a load is operating must be done precisely, because if it is in operation only at night, the length of operating time will vary with the seasons. One small error in estimating time will be cumulative day after day, magnifying the error over the year. This can be critical for installations at high latitudes, but is usually not so important at lower latitudes. The design should ensure that switching devices turn the light on and off at the correct light levels to match the light-on periods used in the solar sizing programme. At higher latitudes there will be a marked seasonal effect on light-on periods.

3.1.1 Photo-sensors

Note that a photodiode (a solar module or separate cell) is more stable than photo resistors, which in time can drift in characteristics, altering the light-on period, and thus adversely affecting the overall power consumption.

If detailed information is not available, the "worst case" situation can be considered and the system designed for the longest winter night.
Estimates for flashed light signal loads must account for the surge current that occurs when heating a cold lamp filament; this will increase the Ah/day consumption. Tables and formulae are available.

3.2 Idling current

Energy efficiency becomes very important in the higher latitudes. For example 5-mA idle current for a lantern during daytime does not seem much, but for autonomy period of 60 days about 7-Ah extra capacity is needed in the battery to allow for the idle current.

3.3 Fog effects on power consumption

In areas where there is often heavy cloud cover or fog the right setting of light turn on and turn off thresholds is important. If threshold for turn off is too high, it is possible that on a cloudy day the turn off of the light is delayed many hours from the intended time, which causes battery depletion.

3.4 Racons

It is more difficult to estimate the power consumption of a Racon than that of a light, because the power consumption depends on the amount of radar equipment in operation in the area and the daly profile of the traffic. It is important to have a sufficient margin when estimating Racon power drain. A separate power system for a Racon is recommended. It reduces the possibility of both the light and the Racon becoming inoperative at the same time.

3.5 Fog signals

Fog signals under fog detector control will need historic fog hour data to predict their operating time, but fog signals are progressively disappearing.

3.6 Remote control and monitoring systems

Remote control and monitoring systems, particularly those with radio communication links, may use considerable power during interrogation. A strict regime must be established to control the time when the link is in operation. [Many monitoring systems allow interrogation from the monitoring centre, and excessive operator-instigated requests for data from a single out-station can cause the energy drain to exceed the design parameters].

3.7 Other loads

Non-essential loads such as domestic lighting must be under some form of automatic control to ensure that they cannot be left on and drain the power system.
Solar sizing programmes usually require loads to be divided into day only, night only and continuous load at different levels of power consumption. Most AtoN lights normally operate only during the night time.

3.8 Typical load levels

The following two tables are taken from the IALA Guideline, produced following the workshop held at Koblenz, Germany in 2001, on new light and energy sources. [Refer to list of references.] They serve to give a guide to typical load levels, and to indicate which load levels allow the use of PV energy.

TABLE 2

Energy required in watt-hours for given load per day

Load	Duty cycle	12 / 24 h	Energy required	Typical AtoN
Watt		operation	Wh/day	
3,000	100	24	72,000	Lighthouse with major load
3,000	50	24	36,000	Lighthouse with major load
3,000	10	24	7,200	Lighthouse with major load
3,000	100	12	36,000	Lighthouse with major load
3,000	50	12	18,000	Lighthouse with major load
3,000	10	12	3,600	Lighthouse with major load
1,000	100	24	24,000	Lighthouse with medium load
1,000	50	24	12,000	Lighthouse with medium load
1,000	10	24	2,400	Lighthouse with medium load
1,000	100	12	12,000	Lighthouse with medium load
1,000	50	12	6,000	Lighthouse with medium load
1,000	10	12	1,200	Lighthouse with medium load
300	100	24	7,200	Lighthouse with low load
300	50	24	3,600	Lighthouse with low load
300	10	24	720	Lighthouse with low load
300	100	12	3,600	Lighthouse with low load
300	50	12	1,800	Lighthouse with low load
300	10	12	360	Lighthouse with low load
100	100	24	2,400	Range lights
100	50	24	1,200	Range lights
100	10	24	240	Range lights
100	100	12	1,200	Major floating aid
100	50	12	600	Major floating aid
100	10	12	120	Major floating aid
30	100	24	720	Range lights
30	50	24	360	Range lights
30	10	24	72	Range lights
30	100	12	360	Beacons
30	50	12	180	Beacons
30	10	12	36	Beacons
10	100	24	240	Racon buoy
10	50	24	120	Racon buoy
10	10	24	24	Racon buoy
10	100	12	120	Lighted buoy
10	50	12	60	Lighted buoy
10	10	12	12	Lighted buoy
Foot note 1	By using modern lamps, i.e. metal halide, halogen and LEDs, the load can be reduced significantly thereby reducing the energy requirement per day resulting in significant cost savings.			

TABLE 3 – Recommended energy source for Aids to Navigation sited at various latitudes

Required energy/day Watt-Hour	Latitude Degrees	*Autonomy, days*	Recommended energy source	Battery capacity Wh	Battery type	Approximate battery cost USD ($)	Comment
10,000	0		Diesel generator	-		-	Autonomy depends on time to repair
10,000	40		Diesel generator	-		-	Autonomy depends on time to repair
10,000	70		Diesel generator	-		-	Autonomy depends on time to repair
3,000	0	5	Solar	15,000	Lead acid	3,750	
3,000	40		Diesel generator	-	Lead acid	-	Autonomy depends on time to repair
3,000	70		Diesel generator	-	NiCd	-	Autonomy depends on time to repair
1,000	0	5	Solar	5,000	Lead acid	1,250	
1,000	40	20	Solar	20,000	Lead acid	5,000	
1,000	70		Diesel generator	-	NiCd	-	Autonomy depends on time to repair
300	0	5	Solar	1,500	Lead acid	375	
300	40	20	Solar	6,000	Lead acid	1,500	
300	70	120	Solar	36,000	NiCd	36,000	
100	0	5	Solar	500	Lead acid	125	
100	40	20	Solar	2,000	Lead acid	500	
100	70	120	Solar	12,000	NiCd	12,000	
30	0	5	Solar	150	Lead acid	38	
30	40	20	Solar	600	Lead acid	150	
30	70	120	Solar	3,600	NiCd	3,600	Foot note 2
10	0	5	Solar	50	Lead acid	13	
10	40	20	Solar	200	Lead acid	50	
10	70	120	Solar	1,200	NiCd	1,200	

Foot notes

1	In all cases, if mains is available, it would be the preferable choice
2	The choice of NiCd is essential due to low temperature
3	For solar AtoN the autonomy includes the battery capacity designed to cover the longest "no sun" period plus (in the case of large "monitored" AtoN) the time to reach the site to complete a repair (MTTR). For diesel powered AtoN the battery autonomy is only the MTTR however the battery may only operate an emergency AtoN for this period.

4 DESIGNING THE SOLAR POWER SYSTEM

4.1 General considerations

The approach taken in sizing the PV power systems may be different in different parts of the world. For a given load or site there is not one correct design solution. For example, increasing the area of PV modules and decreasing battery size is possible and vice versa. Both changes could give valid designs.

4.2 Computer programs

Computer programs allow for many inter-related factors including statistical insolation throughout the year, land and sea reflection coefficients, temperature variations, PV array tilt angle, PV module and battery efficiencies, battery self-discharge, battery electrolyte temperature and accurate electrical load profile. These programs should take account of these factors for each period of the year [typically every month]. Many such programs contain a database of solar insolation data for a large number of global locations.

Some programmes may be pre-loaded with defined solar module and battery characteristics. Less sophisticated programmes may require the operator to interpret the programme output by selecting numbers and ratings of batteries and modules.

Some authorities have developed their own computer programme for design of Photo Voltaic systems dedicated to AtoN, and utilising insolation data for their own respective territories. Others use design programmes from solar module manufacturers.

A detailed knowledge of the solar insolation data for a given site is a primary requirement for accurate system design. Various organisations have gathered insolation data that may be relevant for the area in question.

It is important to compare conditions at the site where published data has been obtained with those at the installation site. Local cloud or mist conditions may considerably affect coastal sites. Local vegetation at land site may mean that the solar energy input is less than the programme might predict. Allowance may have to be made for sand, dust, or industrial deposits on the solar array in some areas.

The problems associated with array sizing increase in the higher latitudes, because variations of energy production and consumption are greater.

4.3 PV energy on buoys

For buoys it is more difficult to size a solar power system, and experience is very important. Some programmes may include rough rules-of-thumb to account for buoy movement and alignment. When choosing a programme to use for solar system design, it may be important for an authority to be sure of what rules are being applied by that programme.

With given data for AtoN on fixed and floating platforms, some authorities have made available the results of their computer sizing programmes and it is interesting to consider the difference in the results. As an example for medium latitude (40º), given solar data, and power consumption, the following table illustrates this variation.

Parameters	Fixed platform 40 W-12V lamp 8.25 duty cycle	Floating platform 10 W- 12V lamp 2.5 duty cycle
Generator peak power (Wp)	100 to 160	60 to 180
Tilting/ Horizontal (degree)	50 to 66	0 to 90
Battery capacity (Ah)*	500 to 250	400 to 150
Autonomy (days)	32 to 10	46 to 10

*The largest battery with the smallest generator

Sizing the solar power system on a buoy is subject to greater variations than one on a fixed structure.

4.4 Availability of computer programmes

Some of the authorities having their own in-house solar sizing programmes are willing to make their programmes available to IALA members, free of charge, but language, and introduction of specific solar data can be obstacles to their use by others.

Some AtoN manufacturers and some solar module manufacturers will carry out Computer design of solar power systems.

Refer also to the list of references.

5 BATTERIES FOR PV ENERGY SYSTEMS

A good starting point when sizing a system is to base the battery Ah capacity on the autonomy required (autonomy being the time the designer wishes the equipment to continue to perform under "no sun" condition – refer to glossary.

5.1 Computing the capacity needed

The required battery capacity is typically calculated by multiplying the maximum daily load in amp-hours/day, by the desired hours (days) of autonomy, divided by the lowest intended state of charge according to the battery technology used (> 0.3), and finally multiplying by a safety factor (around 1.3), which allows for capacity loss during the operational life of the battery, resistive losses etc. This calculation is of course automatically done by PV system software.

5.2 Temperature effects

Note that effective battery capacity will be significantly reduced (by as much as 50%) by high (above 40ºC) or low (below - 5ºC) battery temperature. In hot or cold climates special precautions must be taken to protect batteries from excessive temperature, and battery manufacturers and the customer should acknowledge the operating temperature for the type of battery under consideration.

5.3 Minimum and maximum capacity

The minimum battery capacity will depend on the choice made or imposed for the following design constraints:

- Maximum daily depth of discharge
- Lowest acceptable level of charge during the winter months

- Allowance for “no sun“ days (from meteorological or insolation data). According to the inquiry, 20 days minimum seems a good figure for medium latitude (less in lower latitudes and more in higher ones).
- Ease of access to the AtoN.
- Ability of the battery to accept the peak output of the generator without overcharging, mainly for sealed batteries *(a situation that may arise with a self-regulating system).*

It should be noted that:

- The maximum battery capacity will usually be determined by consideration of cost, available space, weight, and handling capacity. As a general rule the number of batteries in parallel should be kept to a minimum. (Five is a typical figure for good quality batteries coming from the same production batch, installed at the same time and working under the same regime of charge and discharge. It could vary according to the quality of the battery). Some manufacturers offer individual cells or blocks of 2 or 3 cells, with high Ah capacity, and it is usually better to use these in series rather than to parallel smaller batteries.
- Use of lead-acid batteries may require an increase in battery capacity to prevent deep discharge during winter months, but in this situation the effect of low temperature on the battery should be taken into account. For these reasons nickel-cadmium batteries are often preferred for the worst cases (very high latitude and very low temperature).
- Batteries with low self –discharge become important when the design requires a long autonomous period for the system.

5.4 Batteries on buoys

The expected battery life on buoys can be shorter than for a land station, due to shock-load damage of the plates especially for flooded batteries.
Gelled electrolyte batteries are often used on buoys to prevent spillage of electrolyte.

5.5 Battery technology

The following information on battery types is taken from the IALA Guideline, produced following the workshop held at Koblenz, Germany in 2001, on new light and energy sources. Refer to list of references.

5.5.1 Flooded Lead Acid Rechargeable Energy Cells

This is the most common type of rechargeable energy storage medium

Advantages:

- Generally available worldwide
- Relatively inexpensive compared to other storage mediums
- Reasonable storage life - can be stored in dry condition
- Easily disposable – Recyclable
- Easy to check state of charge – SG measurement

Disadvantages:

- Not suitable for very high or very low temperature operation
- Not suitable for regular deep discharge cycles
- Heavy to transport and install
- Corrosive electrolyte
- Difficult to transport in wet condition.

5.5.2 Valve Regulated Lead Acid (VRLA) Battery

5.5.2.1 Absorbed Glass Matt (AGM)

Not recommended for buoys because the attitude of the battery affects its performance. However, these batteries are particularly suitable for fixed aids because they are easy to handle.

Advantages:
- No requirement for topping up
- Minimal maintenance required
- Recyclable
- Safer than flooded lead acid batteries to transport and handle

Disadvantages:
- Shorter Life compared to flooded lead acid - typically 5 – 8 years
- Controlled charging required.
- Limited temperature operation - Reduced life at high temperature
- Difficult to check capacity remaining.

5.5.2.2 Gel Electrolyte

Similar to AGM cells but can be used on buoys, as attitude does not affect performance. The life of these cells are slightly less than AGM cells

5.5.3 Nickel Cadmium

These batteries are preferred for long term use in high and low temperature (will not freeze) and where deep discharge is expected

Advantages:
- Excellent Reliability
- Long cycle life
- Rugged - resists rough handling
- Good charge retention
- Lifetime in excess of 20 years can be expected

Disadvantages:
- Higher initial cost than Lead Acid batteries – Typically more than twice as expensive
- Memory effect on dry cells
- Corrosive electrolyte
- Difficult to transport
- Difficult to dispose of - generally needs to be returned to manufacturer.

5.6 Advances in technology

Battery manufacturers or suppliers should be consulted during AtoN system design, as battery technology is under continuing evolution.

5.7 Quality versus price

It should also be noted that in some areas an acceptable solution may be to use lower-priced batteries and accept that their replacement may be necessary more frequently than for specialist batteries. Such a decision will be influenced by the costs of accessing the AtoN site, and by the ease of fast access in the event of a failure.

5.8 Battery maintenance

Refer to the separate IALA Guideline on batteries, but note that ventilation is required when all types of secondary batteries are being charged.

Even very small solar installations can overcharge a battery given a suitable combination of circum stances. Sealed batteries of all types have some form of a pressure vent and if overcharge they will generate hydrogen in potentially explosive proportions. All battery housings, including buoys, must be effectively ventilated and free from ignition sources.

Safe working practices must be established for opening battery boxes or compartments.

5.9 Charge regulation

A high charge efficiency is needed so that most of the energy produced by the PV array is stored in the battery. A modern electronic charge regulator will generally ensure this.

There are three possibilities for the charge regime:

5.9.1 No charge regulator and conventional PV module.

- Mainly for low latitude and nickel-cadmium batteries
- A lack of a regulator can mean periodical overcharge and gassing of the battery, necessitating frequent topping up with water. This design is not recommended.

5.9.2 Self regulated PV modules

- Usually these are modules with only 32 solar cells, to match the required charging voltage to the battery.
- With self-regulation the battery capacity may need to be increased to prevent frequent overcharging
- With VRLA batteries, the charge rate should not exceed about 1 ampere per 100 amp-hours capacity (C/100 charge rate).
- In hot climates the use of VRLA batteries with self-regulated modules should be avoided.
- The major advantage of using self-regulated PV modules [no charge regulator] is maximum simplicity. In practice the battery is generally not working in the best conditions and its life will be shortened, so that more frequent battery replacement will be needed.

5.9.3 Electronic charge regulator

- Can be either series or parallel type to protect against overcharge or complete discharge
- The advantage of shunt regulation is to avoid a switching component and therefore voltage drop and risk of failure in the battery charging circuit
- Prolongs the battery life and reduces the need for topping up.
- Ensures that the battery is operated within its designed operating specifications.
- Energy however must be dissipated during the regulation period when the battery is fully charged.
- With a series regulator there is only small energy dissipation, but in the case of failure of the switching device the battery will be either overcharged or completely discharged.

- Generally charge regulators have a long Mean Time Between Failures [MTBF]. Static switching (e.g. MOS FET) charge regulators have a very high level of reliability with very low voltage drop.

5.10 Charging parameters

For long battery life, the maximum charge voltage should be set to ensure the battery is fully charged for a significant period of time during summer. This adjustment represents a delicate balance between excessive water consumption and the battery never becoming fully charged.

For a vented battery, some water consumption, apart from evaporation, between the specified topping up levels over a year's operation can be considered normal.

For a “sealed” battery overcharging can mean a loss of capacity. Battery manufacturers’ recommendations should be accurately followed on this point.

The use of a low voltage load disconnect mechanism, or load shedding, is also recommended to prevent premature ageing of the battery and possible failure, which may result from excessive battery discharge. This feature may be included in the load; for example this feature is included in some AtoN lanterns, so that it can be a part of a simple non-regulated, or self-regulated, solar power system. Electronic charge regulators are also available with this feature.

As many charge regulators are based on the measurement of battery voltage it is very important that the voltage measured by the regulator is not concerned with a voltage drop (loss) due to conductor size or poor connections (locking, corrosion). Some charge regulators, especially for larger solar systems, are provided with separate terminals for battery voltage sensing, and require that separate cable cores be run to the battery for this purpose.

The charge control regime should take into account the battery temperature, particularly in high and low temperature applications. The voltage level cut-off is generally defined for 25 C. For instance it should be reduced by a few mV every time the temperature increases by 1 C. Users should refer to battery manufacturer specifications for the exact value. For instance the average value for lead acid batteries is a reduction of 5 mV/deg C/cell.

NiCd batteries require very precise voltage control during charging adjusted for ambient temperature if low water consumption is wanted.

For large PV generators (e.g. greater than 1000 Wp), charge controllers with the following features may help to increase efficiency of the charge to the battery:

- Automatic facility to allow for a cell-equalising charge following deep discharge of the battery.
- Maximum power tracking where the electronic regulator automatically maximise the charge for any level of insolation.
- State of charge indicator connected into the monitoring system.
- Ah or Watt-hour counter.
- Remote monitoring of charging parameters (end-of-charge voltage level, etc).

5.11 Remote monitoring of battery condition

For large PV installations, with significant investment costs, as might be found at lighthouses or major beacons or at installations in high latitudes, remote monitoring and control of the battery parameters can be cost-effective. It allows battery condition to be checked remotely, and remedial action taken as necessary. Sometimes the remedial action may be initiated remotely over the monitoring and control link.

Some regulators are available with a data port output; this is useful for allowing easy connection to a remote monitoring system. Such regulators can provide battery voltage and condition data via the data port.

5.12 Blocking diodes

A blocking diode is used to prevent undesired discharge current from battery to module(s) or through a shunt regulator.

The blocking diode should be of the low voltage loss type, such as a Schottky diode. It is advisable to use one blocking diode per module because only one module would then be affected by a diode failure.

When one blocking diode is used for several modules, a shaded or short-circuited module can become a load for the others. The switching device in a series regulator can save the blocking diode and corresponding energy loss, but in the case of a failure of the switching device, the battery can partially discharge through the PV module. With a shunt regulator, a blocking diode is essential.

A blocking diode should have a minimum direct current value of three times the short circuit current of the module (array) on which it is installed.

6 PRACTICAL CONSIDERATIONS

It should be noted that PV modules that power AtoN, are generally placed in locations with difficult environmental conditions, such as:

- Isolated sites, possibly liable to theft or vandalism.
- Sea locations, with wave impact, storms, corrosion, ice, snow, hail, sand abrasion, and lightning.
- Locations where bird fouling and bird attacks are likely. Birds and animals are known to sometimes attack plastic insulation on cables and plastic encapsulation.

The service life of solar modules can be up to 20 years. Manufacturers commonly offer power output guarantees, and module life guarantees (typically 10 years with maximum 10 % reduction of output power). As with other professional investment decisions, the initial investment costs must be weighed against the costs of maintenance (vehicle, tender, helicopter, and people).

With solar modules having such long service lives, it is desirable to obtain from the manufacturer a guarantee that he will be able to supply modules of identical dimensions in the future, so that modules may be replaced if damaged or stolen. In practice it may be difficult to obtain such a guarantee, and AtoN designers may find it better to buy the best value modules available at the time, and accept that if replacement modules are needed in the future then they may be of different dimensions.

6.1 Installation of modules

6.1.1 Electrical connections

Some manufacturers supply their modules with waterproof junction boxes attached to the back. These can be easier to install than modules with flying leads, and may give better reliability of the electrical connection. For modules with flying leads, care should be taken to properly secure the flying lead, and to ensure that no excessive mechanical load is placed on the lead at the point where it enters the module. Low WG number (Low Wire Gauge number=high square mm) should be used to have reduced resistance and a sufficient mechanical strength.

6.1.2 Fixing

Care should be taken at installation to see that the mounting hardware does not stress the module Prevention against galvanic corrosion between dissimilar metals (frame/structure) using insulators or stand-offs is recommended.

Care should be taken with total or partial shadowing of the modules during the day or any season. Attention should be paid to growing trees, grass, and other equipment.

Note that shadowing of one cell in a module will cause the output from all the cells in that series string to be partially or totally lost.

Devices (special screws or nuts, welded pieces, etc) to dissuade thieves from removing the modules are recommended as well as a notice board indicating the importance of the installation for maritime safety.

In areas where theft is a problem, lanterns with integral solar power systems may be desirable. Remote monitoring is useful to detect intrusion.

6.1.3 Protection from bird fouling

In some areas birds cause real problems by fouling modules. A great number of devices have been devised but the results of the survey in 2000 show that none is totally effective, and bird spikes (plastic or metal) are preferred. Devices working at some places don't work at others. Vertical modules reduce the problem, but imply over sizing. The hazards presented to servicing personnel by metal bird spikes must be considered.

6.1.4 Mechanical protection

Protection to reduce the effect of wave impact, storms, vandalism, theft, and buoy-handling, is generally required. Mechanical backing to the module to reduce the effect of wave impact should be so as not to affect the solar cell temperature and hence efficiency. Efficiency versus mechanical strength should be considered.

A shock-absorbing fender may reduce the effect of impact by a workboat.

Vertical mounting of the modules on a floating aid reduces the vulnerability of the modules.

Metal backing behind the modules, and a clear front cover over the modules might reduce the effect of vandalism, but generally a front cover affects the efficiency because of lower transmission. This effect will increase if the cover is not self-cleaning or becomes dirty.

Metal backing may protect modules that have resin on the back, from bird pecking.

6.1.5 Tilt angle of the module

For fixed installations, the solar array should face the equator. The modules are generally mounted so that the angle between the module and the horizontal varies from being equal to the latitude angle at low latitudes, to the latitude angle plus 20 degrees at high latitudes. To minimise the effects of bird fouling (even with bird protection) and dirt deposits, it is better not to have horizontal modules and tilting should never be less than 20 degrees.

On floating aids, where the orientation of the modules is random, modules are usually distributed around the vertical axis of the buoy (2 at 180°, 3 at 120° etc). Modules mounted at a steep angle, or even vertically, make automatic washing of salt or bird fouling by rain or sea spray more efficient. This also can make integration in the superstructure easier, and protection from damage more effective. The loss of energy at such mounting angles is partially compensated by reflection from the water surface. Some authorities have a policy of mounting single modules horizontally above the lantern on buoys. The horizontal mounting of modules is not recommended for high latitudes.

At medium latitude (45º±5º) 2 vertical modules produce around 1.5 times more energy than one horizontal module with the same peak power. One vertical module produces 0. 7 times the energy of a module which would have been installed so as to have the optimal tilt angle at the worst period.

6.2 Lightning protection

It can be said that no protection is better than a bad protection system.
A protected station should have its lightning protection system checked every year.
A current practice is to ground (earth) the metallic frames of all equipment - electric conductors are left floating.
On non-metal buoys, an air terminal on the top, directly connected to the mooring chain, can limit damage from lightning.
If the voltage of the PV generator is above 50 V, it is suggested practice to ground one conductor (generally the negative one).
Refer to the IALA Guideline.

7 MAINTENANCE

Maintenance of a PV power system at an AtoN should, of course, be planned as part of a total maintenance programme for all components of the AtoN site.

7.1 Programmed maintenance

For the PV power system, maintenance will probably include some or all of the following.

- Battery top-up as necessary.
- Check state of charge, open-circuit voltage and loaded voltage, and specific gravity and the general condition of the battery. [Measuring of specific gravity applies to flooded Lead Acid batteries only]
- Check external aspect of the battery plates and accumulation of sediment when batteries with transparent cases are used.
- Inspect the PV modules for corrosion [especially at the inter-cell connections and at the uotput terminals], discoloration of the encapsulant, de-lamination, and bird fouling.
- Confirm load demand is within specified limits.
- Check of connections and condition of cables.
- A check should be made for changes in environmental conditions, which may result in shadowing of the PV modules. I.e. trees, new buildings etc.
- Routine cleaning, and the greasing of battery terminals.

Solar modules should not need maintenance, only inspection and cleaning.

7.2 PV module degradation check

The performance of PV modules may be checked at longer intervals by using a reference solar cell (to test at minimum the short circuit current and the open circuit voltage for each module). To avoid destruction or accident a specialist should do this test.

7.3 Frequency of maintenance visits

In many locations, one maintenance visit per year should be adequate for a correctly designed system. There might be some sites where industrial fall-out, wind-carried sand, or a high bird population requires a more frequent schedule. In some hotter climates it may be better to visit twice per year for battery top-up.

However two visits per year, especially for a recently installed station, is a good practice:

- One visit in the autumn to ensure the battery is fully charged and the PV array in good condition.

- One visit in the spring to correct any damage after the winter period, to add water to the batteries (if flooded type), and to be sure the array can fully charge the battery during summer.
- After that it should be possible to move to an annual inspection.

With experience, it can be possible to extend inspection periods to one or more years for many installations.

8 TRAINING OF MAINTENANCE PERSONNEL

A PV system is a crucial part of an AtoN system and the Authority should therefore make sure that the people who service such a system are already been made fully aware of how it operates. They should also sufficiently understand the system operating principles so they are able to determine why components may fail. They should also be aware of what may be dangerous actions when servicing such an installation. Normally the potential risk to personnel will increase with the size of the system. Care with batteries should be well covered in any training course.

The following should therefore be included as part of a training programme:

- Explanation of how a solar module works, including the meteorological variability of solar irradiation.
- The purpose of blocking diodes
- How a solar module is built, and how it should look when it is in a proper condition
- If a charge regulator is used, the charge regulator should be explained and demonstrated
- The battery's electro-chemical principles, and how it should be properly maintained.
- Safety with batteries. Special training should be given on how to handle the electrolyte properly, including protective clothing and goggles, in order to prevent any accident.
- A special note should be developed covering how to deal with hydrogen [and other dangerous gases] and how it behaves and how it should be ventilated accidents.
- The service personnel should be trained in how to identify a fault in the system.
- The service personnel should be trained in taking measurements and performing regular maintenance on the system.
- A routine procedure should be developed so that the responsible person can obtain the necessary information when the service work is undertaken. [A record keeping and reporting system should be established.]
- Relevant occupational safety and health regulations should be included as part of the training programme.

9 SOURCES OF REFERENCE DATA

IALA has published other documents related to solar systems:

- IALA specification for solar-photovoltaic systems, June 1988
- IALA practical notes on the application of solar power systems for aids to navigation, September 1993
- IALA Guidelines for renewable energy sources for marine aids to navigation solar-photovoltaic systems, October 1997
- IALA Guidelines on a standard method for defining and calculating the load profile of Aids to Navigation
- IALA Guidelines on maintenance and operation of batteries, December 2001
- IALA Guidelines on new light sources and associated power supplies, December 2001
- The IALA Engineering Committee has also prepared *Functional specification to develop a computer program for sizing solar (photo voltaic) power systems*
- IALA Guideline for the protection of lighthouses and aids to navigation against damage from lightning, December 2000.

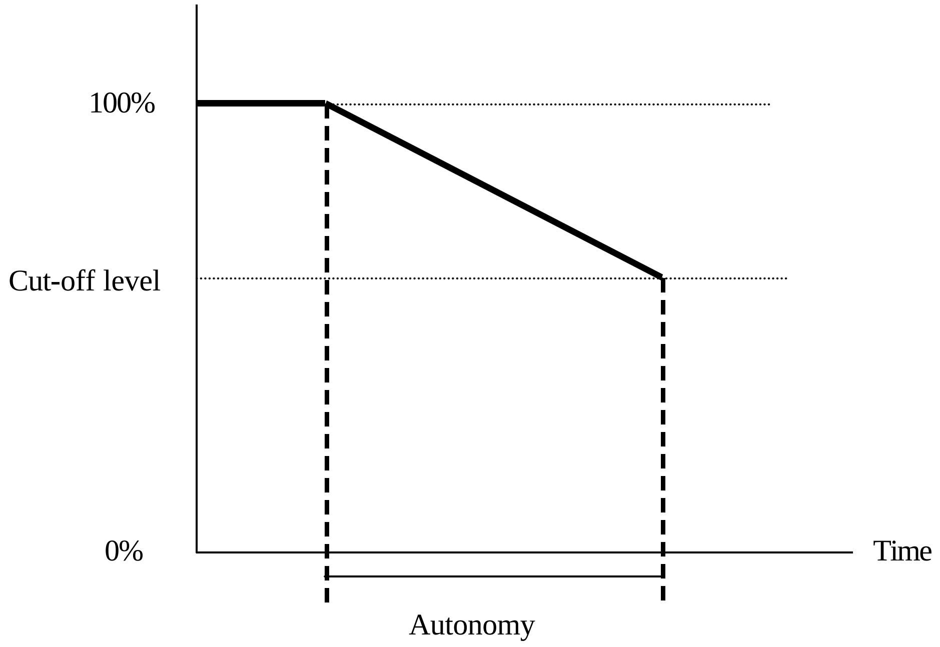
10 SOLAR PHOTOVOLTAIC GLOSSARY

Note that the terms relating to the solar photovoltaic part of the system are extracted from IEC TC 82 “Solar photovoltaic energy systems Guide: Glossary of terms and symbols used in solar photovoltaic energy systems - part I - 82/154”.

Attention is drawn to the IALA Dictionary, chapter 6, power Supplies for stations. Section 2, Natural Energy Sources and Low Level Sources. Also Section 4 Electrochemical cells and batteries.

Array:
A mechanically integrated assembly of modules or panels together with support structure but exclusive of foundation, tracking, thermal control and other such components, to form a DC power producing unit.

Autonomy of a battery:
The autonomy of a battery is a theoretical concept. It indicates the time in days (or hours) a battery will take to discharge from a fully charged state [100 % state of charge (SOC)] to a chosen cut-off level state of charge, powering the AtoN system **without** any energy coming from the generator.
The cut-off level is chosen by the designer according to the battery technology used.
It must be noted that the electrical power consumed by the AtoN system (in Ah/day or Wh/day) may vary with weather conditions and/or season of the year. It is recommended to use the worst conditions (night duration & temperature) to calculate the battery autonomy.



Conversion efficiency:
The ratio of maximum electrical power output to the product of photovoltaic device area and incident irradiance measured under defined test conditions and expressed as a percentage.

Current-voltage characteristics (I = f (V)):
The output current of a photovoltaic device as a function of output voltage at a particular temperature and irradiance.

Fill Factor (FF) :
The ratio of maximum power to the product of open-circuit voltage and short-circuit current

$$FF = \frac{P\max}{Voc * Isc}$$

Irradiance:
(WmÎ^2) radiant power incident upon unit area of surface.

Irradiance, Direct (Wm ^{2}):
The radiant power from the sun's disc and from a small circumsolar region of the sky within a subtended angle of 5° incident upon unit area.

Irradiance, Diffuse : (Wm ^{2}):
The total radiant power incident upon a unit area excluding the direct irradiance.

Irradiation :
Integration of irradiance over a specified period of time. (MJmÎ^2 per hour, day, week, month, year as the case may be).

Module :
The smallest complete environmentally protected assembly of cells.

Module area:
The entire frontal area of the module, including borders and frame (m^2).

Module packaging efficiency:
The ratio of the total cell area to module area.

Panel :
A group of modules fastened together, pre-assembled and wired, designed to serve as an installable unit in an array and/or sub-array.

Panel area (m^2):
The entire frontal area of the panel, including modules, inter-module framework and spacing.

Panel packing efficiency:
The ratio of the total module area to panel area.

Photovoltaic effect:
Direct conversion of radiant energy into electrical energy.

Photovoltaic (PV) System:
An installed aggregate of components and subsystems that combine to use the photovoltaic effect to convert solar energy into electrical energy suitable for connection to an application load. In its simplest form a PV system consists of a PV array with connections to the load, but it may also include power conditioning, monitoring and control equipment, energy storage and power distribution units.

Rated current:
The measured value of current of a PV device at rated voltage under Specified Operating Conditions.

Rated maximum power:
The value of maximum power of a photovoltaic device under Specified Operating Conditions.

Rated power:
The value of power output of a photovoltaic device at rated voltage under Specified Operating Conditions.

Rated voltage:
The voltage at which a PV device is designed to produce near maximum electrical power under Specified Operating Conditions.

Reference solar cell:
A solar cell used to measure irradiance or to set simulator irradiance levels in terms of a reference solar spectral irradiance distribution.

Short circuit current (Isc):
The output current of a photovoltaic device in the short-circuit condition at a particular temperature and irradiance.

Solar cell:
The basic photovoltaic device that generates electricity when exposed to sunlight.

Solar cell area:
The entire frontal area of the solar cell, including the cell grid (cm^2).

Spectral response (absolute) (S abs):
The short circuit current density generated by unit irradiance at a particular wavelength (AWÎ^1), plotted as a function of wavelength.

Spectral response (relative) (S rel):
The spectral response normalised to unity at wavelength of maximum response.

Voltage temperature coefficient:
The change of the open circuit voltage of a PV device per degree Celsius change of cell temperature. This coefficient varies with irradiance and to a lesser extent with temperature.

11 RESULTS OF THE USER SURVEY IN 2000

During the year 2000, IALA sought information from its members via a questionnaire on energy sources, with the objective of generating some statistics relating to the use of various energy sources for AtoN, particularly PV energy sources.

11.1 Respondents

The countries which answered the inquiry covered all latitudes from 0° to 80° North and South and represented operators of

- 30,425 floating aids and
- 44,044 fixed aids.

Readers should also remember that despite the reasonably large numbers of respondents to the questionnaire in 2000, the results are necessarily affected by some authorities having large numbers of AtoN in service compared with the numbers of other authorities. Note that the results are analysed by numbers of AtoN, not by numbers of Authorities.

11.2 Summary of main conclusions

As a result of an analysis of the returned questionnaires, it appears that in 2000, for the AtoN operated by the respondents to the survey:

- 49% of fixed aids and 30.6% of floating aids were powered by solar PV systems.
- 12.6% of fixed aids were powered from the public utilities supply.
- 3.3% of fixed aids and 8.2% of floating aids were powered by primary cells (not rechargeable) mainly in the countries operating floating AtoN above 60' latitude.
- 1.2% of fixed aids and 2.3% of floating aids were powered by gas (mainly acetylene).
- 1.2% of fixed aids were powered by diesel generators.
- 0.1% of fixed aids were powered by kerosene.
- 0.3% of fixed aids and none of the floating aids were powered by wind-powered generator.
- Only a tiny number of AtoN utilised wave, seawater battery or other unusual power sources.
- Very few fixed AtoN had hybrid sources. These were mainly solar PV with diesel generator back-up and very occasionally also with wind back-up. Some were PV with wind back-up.
- A small number (less than I %) of floating AtoN had hybrid sources mainly PV and wave, or PV and primary cells.

11.3 Tabular summary - load

Analysis of the survey information showed that the averaged load values were as follows.

Parameters	Fixed			Floating		
	Min	Typical	Max	Min	Typical	Max
Average power of the load (Watt)	3	21	50	3	10	22
Max. power of the load (Watt)	5	181	1000	5	25	100
Min. power of the load (Watt)	1.5	7	20	2	7	10
Average duty cycle	0.1	0.2	0.5	0.1	0.21	0.5

Average power of the load: Ó (P lamp x duty cycle) / total number of AtoN under consideration.

Average duty cycle: Ó (duty cycle) / total number of AtoN under consideration

11.4 Tabular summary - batteries

Analysis of the survey information showed that the averaged battery capacities were as follows.

Parameters	Fixed			Floating		
	Min	Typical	Max	Min	Typical	Max
Average capacity (Ah)	100	310	500	100	285	1000
Technology	Lead-acid flooded preferred (56%)			VRLA preferred (81%) generally gelled electrolyte except for freezing sites.		
Average autonomy without solar production in days	4	30	120	10	45	90
Battery conditioning				Generally vented container in buoy superstructure (30 %)		
Average duration life in years at 75% of nominal capacity at the end of life	4	9	20	3	5	10

11.5 Tabular summary - typical solar generator sizes

The results, covering a total of 840 kWp installed module power, showed the following for the averaged peak Watts figure for the PV generator.

	Fixed			Floating		
	Min	Typical	Max	Min	Typical	Max
Average power per AtoN (Wp)	20	186	833	20	89	300
Largest generator (Wp)	100	1495	4400	30	256	3500
Smallest generator (Wp)	3	22	48	3	41	300
Peak power of the generally used modules (Wp)	10	50	80	10	50	80
Tilting angle	Latitude + 15°			Generally more than 60º (sometimes horizontal)		