

# **IALA Guideline No. 1042**

**On**

## **Power Sources for Aids to Navigation**

**Edition 1**

**December 2004**

**(Replaces IALA Guidelines on Solar Photovoltaic  
Systems for Aids to Navigation, December 2001)**



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# Table of contents

<b>1</b>	<b>INTRODUCTION .....</b>	<b>5</b>
<b>2</b>	<b>SELECTION OF POWER SYSTEMS AND ENERGY STORAGE .....</b>	<b>5</b>
2.1	GENERAL .....	5
2.2	GUIDANCE ON POWER SOURCES .....	5
2.3	USER REQUIREMENTS .....	7
2.4	AUTOMATION .....	7
<b>3</b>	<b>CALCULATING THE TOTAL ELECTRICAL LOAD .....</b>	<b>7</b>
3.1	LOAD OPERATING TIMES .....	8
3.2	PHOTO-SENSORS .....	8
3.3	IDLING CURRENT .....	8
3.4	FOG EFFECT ON POWER CONSUMPTION .....	8
3.5	RACONS .....	9
3.6	REMOTE CONTROL AND MONITORING SYSTEMS .....	9
3.7	AIS .....	9
3.8	OTHER LOADS .....	9
3.9	TYPICAL LOAD LEVELS .....	9
<b>4</b>	<b>POWER GENERATION .....</b>	<b>12</b>
4.1	AC MAINS POWER .....	12
4.2	SOLAR POWER - PHOTOVOLTAIC CELLS .....	12
4.3	GAS LANTERNS AND LIQUID PETROLEUM GAS (LPG) .....	12
4.4	DIESEL GENERATORS .....	13
4.5	PETROL ENGINE GENERATORS .....	13
4.6	FUEL CELLS .....	13
4.7	WIND ENERGY .....	14
4.8	WAVE ACTIVATED GENERATOR (WAG) .....	14
<b>5</b>	<b>ENERGY STORAGE .....</b>	<b>15</b>
5.1	PRIMARY BATTERIES .....	15
5.2	SECONDARY BATTERIES .....	16
5.3	NICKEL CADMIUM .....	17
5.4	NICKEL METAL HYDRIDE .....	18
5.5	LITHIUM ION .....	18
<b>6</b>	<b>PHOTOVOLTAIC (PV) SYSTEMS .....</b>	<b>19</b>
6.1	CONVERSION OF EXISTING LIGHTS TO PV ENERGY .....	19
6.2	PV MODULE TECHNOLOGY .....	19
6.3	SECONDARY ENERGY SOURCES .....	20
6.4	SOLAR SIZING DESIGN COMPUTER PROGRAMS .....	20
6.5	BATTERIES FOR PV ENERGY SYSTEMS .....	21
6.6	PRACTICAL CONSIDERATIONS .....	25
6.7	INSTALLATION OF MODULES .....	26
6.8	MAINTENANCE .....	27
6.9	TRAINING OF MAINTENANCE PERSONNEL .....	28
<b>7</b>	<b>OTHER TECHNOLOGIES IN THE AREA OF AIDS TO NAVIGATION .....</b>	<b>29</b>
7.1	SEAWATER BATTERY .....	29
7.2	CURRENT AND TIDAL TURBINES .....	29
7.3	STIRLING ENGINE GENERATORS .....	29
7.4	THERMO ELECTRIC GENERATOR .....	30
<b>8</b>	<b>LIFE CYCLE MANAGEMENT CONSIDERATIONS .....</b>	<b>30</b>

<b>9</b>	<b>REFERENCES.....</b>	<b>31</b>
9.1	IALA RELATED DOCUMENTS .....	31
9.2	RELEVANT IEC STANDARDS.....	32
	<b>ANNEX 1 - SOLAR PHOTOVOLTAIC GLOSSARY.....</b>	<b>33</b>
	<b>ANNEX 2 - RESULTS OF THE YEAR 2000 SURVEY OF THE USE OF PV ENERGY SYSTEMS BY IALA MEMBERS.....</b>	<b>36</b>
<b>1</b>	<b>RESPONDENTS.....</b>	<b>36</b>
<b>2</b>	<b>SUMMARY OF MAIN CONCLUSIONS.....</b>	<b>36</b>
2.1	TABULAR SUMMARY – LOAD.....	37
2.2	TABULAR SUMMARY – BATTERIES.....	38
2.3	TABULAR SUMMARY - TYPICAL SOLAR GENERATOR SIZES .....	38



## **1 Introduction**

The purpose of this Guideline is to assist Authorities in the design of power systems and energy storage for Aids to Navigation (AtoN), with emphasis on proven technologies.

This guideline contains descriptions of power supplies that are available for use with AtoN, together with their advantages and disadvantages. Suggestions on Life Cycle Management issues are also addressed in the document.

## **2 Selection Of Power Systems And Energy Storage**

This section identifies those items that should be taken into consideration when selecting energy storage and associated power supplies for AtoN. Table 1 provides guidance on the most appropriate power systems for a number of locations, power requirements and environmental issues.

### **2.1 General**

The power requirement for AtoN cannot be based on the light source in isolation because the power system provides for the total needs of the AtoN. This may include fog signals, lights, racons, remote control and monitoring facilities, security and domestic loads. Domestic loads can vary substantially - demand on manned stations will be at a constant high level, while the demand on unmanned stations would only occur during routine maintenance visits.

In addition to the development of new light sources, the automation of lighthouses and systems and changing user requirements play a significant part in the relevance and size of power supplies.

However, developments in technology have made it possible to reduce the power consumption of AtoN without any detrimental effect on the service provided to mariners. In particular, battery systems rather than diesel generators can be used as back up for mains power or as the companion of renewable energy sources.

### **2.2 Guidance on Power Sources**

Where mains power is readily available and reliable, this may be the cheapest energy source. When mains power is used, it is sufficient to provide back-up facilities by means of a float charged secondary battery. The capacity of the battery need only be sufficient to enable time for access to site and repair.

Where mains power is difficult or impossible to install, solar energy should be considered as the next option. In situations of light loads where solar power is not practicable, primary batteries can be used.

Diesel generators should only be considered for major loads.

Table 1 provides information on the practical choice of energy storage systems and guidance on the application of power sources for aids to navigation.

**TABLE 1**

**Selection Guide of energy storage and associated power systems**

Power Systems	Remote Site	No Easy Access	High Power > 300 Wh / day	Medium Power 300 - 100 Wh / day	Low Power < 100 Wh / day	Extreme Temperatures	Ventilation not possible	Buoy	Major Floating Aid	Life Expectancy (estimated years)
<b>Mains power</b>	+o	+	++	++	+	++	++	-	-	-
<b>Diesel generator</b>	+	o	+	-	-	o	o	-	-	20
<b>Solar</b>	++	++	-	+	++	++	-	++	++	20
<b>Wind generator</b>	++	-	++	+	o	-	-	o	o	1 to 15
<b>Fuel Cell</b>	++	-	+	++	++	-	o	-	-	15
<b>Lead acid</b>	+	+	+	+	+	-	-	o	+	
<b>Sealed lead acid</b>	++	o	-	o	+	-	-	++	+	
<b>VRLA</b>	+	o	o	+	+	-	-	o	-	
<b>Pocket NiCd</b>	++	o	+	+	+	+	-	o	+	
<b>Sintered NiCd</b>	+	o	+	+	+	+	-	o	+	
<b>Sealed NiCd</b>	++	o	+	+	+	+	-	++	+	
<b>Air depolarized</b>	o	o	-	-	+	o	-	+	o	
<b>Alkaline</b>	o	o	-	-	+	o	++	+	o	
<b>Zinc-Carbon</b>	-	o	-	-	+	-	++	+	-	
<p>++ <i>Recommended solution</i>                      +o Recommended solution where mains power is available                      + <i>Good solution</i>                                      o <i>Not recommended</i>                                      - No comment</p>										

## **2.3 User Requirements**

The user requirement also has an important part to play in power consumption. For every mile reduction in range for lights the required luminous intensity is roughly halved and hence power consumption reduced. The application of visual and audible AtoNs is changing, ranges are being reduced considerably, resulting in far less power demand.

## **2.4 Automation**

Automation takes away the constant domestic element but introduces control devices to ensure equipment is on when required, and the converse being that the same device will also switch off the AtoN when not required, thus saving power. Typical examples are day/night sensing for the light sources, fog detectors for fog signals and state of charge sensors for diesel generators.

### **2.4.1 Disadvantages**

The continual reduction of power consumption and thus the requirement for smaller power supplies has distinct advantages, but where this is applied to buildings that were originally occupied, there are disadvantages that should be recognised and addressed.

Such buildings had facilities for heating to levels comfortable to the keepers. With automation, if the level of power available was based only on the consumption needed to operate the AtoNs, there would be no spare capacity for the protection of the fabric of the building. This may result in damp conditions leading to the deterioration of the building itself as well as the AtoN equipment.

Where mains power is available heating or dehumidification can be provided without increasing the back up power supply. However, with renewable energy or hybrid operated systems there is no spare capacity for building conditioning, as this would defeat the savings made. In these cases alternatives need to be considered including:

- Improved ventilation.
- Good building maintenance.
- Ancillary powered heating either by high efficiency gas or diesel fired boilers, solar or wind generators.
- High efficiency Stirling cycle engine to provide heating as well as electrical power.

## **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 includes power consumption and efficiency of the:

- light source and optic equipment;
- control system; 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 should be as accurate as possible, noting that, if the AtoN is operating only at night, the length of operating time will vary with the seasons.

One small error in estimating load operating time will be cumulative day after day, magnifying the error over the year. This can be critical for installations at high latitudes, but may not be as important at lower latitudes. If detailed information is not available, the "worst case" situation can be considered and the system designed for the longest winter night.

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 calculating programme. At higher latitudes there will be a marked seasonal effect on light-on periods.

Estimates for flashed light signal loads should 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 in IALA Guidelines on a Standard Method for Defining and Calculating the Load Profile of Aids to Navigation, Dec. 1999.

IALA Guidelines on Ambient Light Levels at which AtoN lights should be switched on and off (Dec. 2004) and IALA Guidelines on Designing Solar Power Systems for Aids to Navigation (Dec. 2004) also refer.

### **3.2 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.

### **3.3 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.

### **3.4 Fog Effect on Power Consumption**

In areas where there is often heavy cloud cover or fog the correct threshold setting of light switch-on and switch-off 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.

#### **3.4.1 Fog Signals**

Fog signals under fog detector control will require historic fog hour data to predict their operating time. It should be noted that fog signals are progressively disappearing.

### **3.5 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 radar activity in the area and the daily profile of the traffic. It is important to allow a margin when estimating Racon power drain. A separate power system for a Racon is recommended, as this reduces the possibility of both the light and the Racon becoming inoperative at the same time.

### **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 should 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 AIS**

AIS has the potential to replace or augment existing remote control and monitoring systems, as well as to provide AtoN service in its own right. IALA Recommendation A-126 on the use of AIS for AtoN refers. However, the power consumption is proportional to the amount of information transmitted, and consideration should be given to such parameters as:

- The transmitted power.
- The number and types of messages to be transmitted.
- The message repetition interval.

AIS transponders are under development and users should consult the manufacturers for the load profile.

### **3.8 Other Loads**

Non-essential loads such as domestic lighting should be under some form of automatic control to ensure that they cannot be left on and drain the power system.

Solar sizing or calculating 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 night-time. IALA Guidelines on Designing Solar Power Systems for Aids to Navigation (Dec. 2004) refers.

### **3.9 Typical Load Levels**

The following tables (Table 2 and Table 3) provide guidance on typical load levels, and indicate which load levels allow the use of Photovoltaic (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.			

IALA Guideline No. 1042 – December 2004  
Power Sources and Energy Storage for AtoN

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

Required energy/day Watt-Hour	Latitude Degrees	<i>Autonomy, days</i>	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 Power Generation

### 4.1 AC Mains Power

The availability of AC mains power at or near the site should be the first consideration.

**Advantages:**

- Load on the system is not critical.
- Low cost.
- Low maintenance.

**Disadvantages:**

- Possible unreliability of the AC power supply.
- Addition of a back up system that will need periodic maintenance.

**Comment:**

- Interference from lightning strikes is a possibility that should be considered. IALA Guidelines on Protection of Lighthouses and AtoN against Damage from Lightning, June 2000, refer.

### 4.2 Solar Power - Photovoltaic Cells

When properly designed, solar power systems are very reliable and are the most widely used renewable energy source for charging storage batteries. If mains AC are not available, reliable or too costly, solar power should be the preferred solution

**Advantages:**

- No moving parts.
- Low technical maintenance.
- Long life.
- Well proven technology.
- Very low operational costs.

**Disadvantages:**

- Deterioration of energy due to effects of the environment e.g. Sand, Dust, Bird fouling, Salt, etc.
- Susceptible to vandalism and theft.
- Large area required on some sites to generate sufficient energy.
- Cost of systems increases rapidly in high latitudes (above 55 degrees North/South) due to low insolation.
- Susceptible to wind and wave damage.
- Corrosion of PV module frames and terminals.

**Comments:**

- For detailed information on photovoltaic systems see section 6.

### 4.3 Gas Lanterns and Liquid Petroleum Gas (LPG)

Formerly gas lanterns were used, particularly on buoys, due to the high reliability of the systems. However, due to high overall maintenance costs consideration should be given to installing solar powered low maintenance systems. When a gas system is being considered as a power source for AtoN, the availability of a reliable gas supply and spare parts should be identified.

**Advantages:**

- None.

**Disadvantages:**

- Expensive to purchase and operate.
- Large storage space required for low power output.
- Hazardous nature of the fuel creates personnel safety and environmental risks.

**Comment:**

- This technology is being phased out in most countries.

#### **4.4 Diesel Generators**

Generally used for high power requirements on fixed AtoN at remote places or as backup for mains electricity.

**Advantages:**

- Good cost to power ratio.
- Long established technology.
- Power is independent of most weather conditions.

**Disadvantages:**

- Complexity of installation.
- Dedicated space required, i.e. engine room needed.
- Expensive to maintain.
- Produces noise and atmospheric pollution.
- Regular refuelling required.
- Unattended service interval is short, typically 4 – 6 months.
- Fuel storage environmental risk has to be addressed at each site.

**Comments:**

- Renewable energy systems should be used in place of diesel generators wherever possible. Diesel generation may provide the reserve part of a hybrid system, or may be provided as an emergency power source.
- Installation of a diesel generator system may be considered necessary where domestic power is required.

#### **4.5 Petrol Engine Generators**

Generally these power systems are used in a manner similar to the diesel generator systems described in section 4.4.

**Advantages:**

- Refer to Diesel Engine Generators.

**Disadvantages:**

- Refer to Diesel Engine Generators.
- Fuel storage and transport safety implications.
- Less durable than diesel engine generators.
- Additional and more frequent service requirements.

**Comment:**

- For these reasons petrol engine generators are not recommended for fixed installations.

#### **4.6 Fuel Cells**

Fuel cell technology is quite new and is under continuous development. The fuel cell can be used as primary energy source or in combination with PV or wind generator (Hybrid System) on AtoN in remote areas.

**Advantages:**

- No moving parts in the Proton Exchange Membrane (PEM) cell.
- Low tech maintenance.
- No pollutant emissions.
- Low operational costs.

**Disadvantages:**

- Refuelling problems.
- Low temperature performance for some types.

**Comment:**

- There are two types of fuel cells available on the market relevant to AtoN.
  - *PEM (hydrogen as fuel)*  
The PEM can be used on medium and major fixed lights in remote areas.
  - *Direct Methanol Fuel Cell*  
This technology still has to be proven in AtoN for small and medium lights, as well as buoys.

#### **4.7 Wind Energy**

Wind energy is an option where the power required cannot be achieved alone by solar power, or as replacement for diesel generator.

**Advantages:**

- Easy to install.
- Power available where low insolation prevents use of solar PV generation.
- Renewable energy source with associated cost savings.

**Disadvantages:**

- Very high technical maintenance using currently available machines.
- Site dependant.
- Subject to damage under local weather conditions, e.g. freezing rain, typhoon.

**Comment:**

- The wind generator can be used as primary source of power generation but it should be considered to have some form of backup power source. Permission may be required for siting of the wind turbine.

#### **4.8 Wave Activated Generator (WAG)**

Wave activated generators are used on tail-tube buoys or combined with solar power.

**Advantages:**

- Relatively high energy density in floating AtoN with typically 60 - 100W output power.
- Renewable energy source with associated cost savings.

**Disadvantages:**

- Normally be used on tail-tube buoys, which maybe inconvenient to handle.
- High capital cost.

- High maintenance cost - typically installations are serviced at yearly intervals.
- Limited availability – single source.
- Flora and fauna might limit the use of some types of WAGs.

**Comment:**

- Technology still under development.

## **5 Energy Storage**

### **5.1 Primary Batteries**

Over-current protection is recommended on battery packs.

#### **5.1.1 Air Depolarised Dry Batteries**

**Advantages:**

- High output but increasing cost.
- Good shelf life (can be as little as, 8% deterioration in 2 years).

**Disadvantages:**

- Air breathing is required; limiting installations to mostly shore based AtoN or buoys with carefully designed ventilation. Disposal is a further consideration.

#### **5.1.2 Zinc Carbon**

These are being superseded with alkaline types.

**Advantages:**

- Cheap and reliable sealed types require no maintenance and batteries for stand-alone applications such as buoys, beacons and Racons, but are increasingly unavailable in parts of the world.
- Secure power supply applications such as security systems.

**Disadvantages:**

- Short shelf life.
- Limitation in output power result in the zinc carbon being limited to 10W output power on a flashing character.
- Often not more than 20% load factor is available.
- Poor low temperature service capacity.
- Disposal is a further consideration.

#### **5.1.3 Sealed Alkaline Battery**

The higher cost of sealed alkaline batteries compared with zinc carbon batteries can be justified if this cost is offset by lower maintenance costs.

**Advantages:**

- Very useful in operating buoy lights and other applications requiring sealed secure operation.
- Good low temperature performance.

**Disadvantages:**

- High cost, generally low voltage per unit meaning multiple sets of these batteries are needed to make 12V systems.
- Disposal is a further consideration.

**5.1.4 Lithium**

Different technologies of lithium have different safety features.

**Advantages:**

- Low weight and high-energy availability in a small space. Sealed operation allows operation even under water.

**Disadvantages:**

- Production of dangerous gases with consequent environmental concerns, including explosions, prevents this type of battery from being recommended unless a rigorous safety regime is introduced.
- Disposal of Lithium batteries is extremely difficult and costly however this service may be built into the purchase price.

**5.2 Secondary Batteries**

The batteries included in this section are those generally available for use with AtoN power generation systems. Some ventilation is required when ALL types of secondary batteries are being charged.

- Over-current protection is recommended.
- Return to supplier or approved agent for disposal is recommended.
- Install and operate in accordance with manufacturers instructions.

**5.2.1 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.
- Higher energy exchange efficiency compared to Nickel Cadmium cells (95% v 80%).
- 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.
- Needs adequate ventilation.
- Dangerous contents (corrosive electrolyte and potentially explosive gas).
- Difficult to transport in wet condition.

- Electrolyte spilled if battery tilted.
- Lead is regarded as a hazardous material in some parts of the world.
- Large battery charged by small PV array – stratification may occur.

### **5.2.2 Valve Regulated Lead Acid (VRLA) Battery**

These batteries are particularly suitable for fixed and floating AtoNs because only a small amount of ventilation is required and they are easy to handle.

#### **5.2.2.1 Absorbed Glass Matt (AGM)**

##### ***Advantages:***

- No requirement for topping up.
- Minimal maintenance required.
- Recyclable.
- Energy efficiency.
- Safer than flooded lead acid batteries to transport and handle as less likely to spill.
- High rate of charge is possible.
- There is no memory effect on the depth of discharge.
- Good low temperature performance.

##### ***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.
- Deep discharge not recommended.
- Ventilation must be provided.
- Dangerous contents (corrosive electrolyte and potentially explosive gas).
- Lead is regarded as a hazardous material in some parts of the world.

#### **5.2.2.2 Gel Electrolyte**

Similar characteristics to AGM cells. No liquid electrolyte to spill. AGM is preferred for colder climate.

### ***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:***

- Good high and low temperature performance.
- Excellent reliability.
- Long cycle life.
- Rugged - resists rough handling.
- Good charge retention.

- Lifetime in excess of 20 years can be expected.
- Excellent recovery from deep discharge.

**Disadvantages:**

- Disposal consideration - Cadmium is regarded as a hazardous material in some parts of the world.
- Higher initial cost than lead acid batteries – typically more than twice as expensive.
- Memory effect on dry cells.
- Low energy density.
- Needs adequate ventilation.
- Periodic topping up required – newer recombination cells do not require topping up.
- Dangerous contents (corrosive electrolyte and potentially explosive gas).
- Difficult to transport.
- Difficult to dispose of - generally needs to be returned to manufacturer.

#### **5.4 Nickel Metal Hydride**

Technology presently being tested 1.2 kWh blocks.

**Advantages:**

- Charging performance similar to Lead Acid and Nickel Cadmium.
- High energy density / light weight.
- Disposal good compared with Nickel Cadmium.
- Life expectancy in order of 15 years.

**Disadvantages:**

- Cost double Nickel Cadmium.

#### **5.5 Lithium Ion**

Technology in fast pace of development but unproven. Presently being tested (11.1V, 30Ah power cells or 45Ah energy cells).

**Advantages:**

- High energy density / light weight.
- Disposal good compared with Nickel Cadmium.
- Life expectancy in order of 20/25 years.
- Extended temperature range.
- Monitor state of discharge.
- Low self discharge.
- High charging efficiency.

**Disadvantages:**

- Non-standard cell voltage of 3.7V.
- Complex charging circuitry.
- High initial cost.

## **6 Photovoltaic (PV) Systems**

More than 50% of AtoN are powered using PV systems and the trend is for increasing usage.

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 no one correct design solution. For example, increasing the area of PV modules and decreasing battery size may be possible and vice versa.

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 with due consideration for protection from the marine environment, PV power systems are very reliable and are the most widely used renewable energy source for charging secondary batteries.

### **6.1 Conversion of Existing Lights to PV Energy**

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

### **6.2 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, tedlar, or metal backing. Amorphous silicon PV modules are less efficient, have progressive reduction in power output with a lower life expectancy, and therefore, are not generally recommended for AtoN applications.

All single crystalline or multi-crystalline technologies are the subject of continuing research driven by grid connection systems, leading to reduction in cost. Marine modules are, however, produced in smaller quantities with attention paid to the specialised environmental packaging.

From a life cycle management point of view, this is of benefit in providing the required level of service.

#### **6.2.1 Modular Design Considerations**

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

If the installation consists of more than one AtoN, or a combination of AtoNs 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 AtoN has the advantage that if the power to one AtoN fails, the other AtoNs will continue to operate normally, but such a system will have a higher initial cost, and will require slightly 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 used to meet the operational availability.

### **6.2.2 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.

### **6.3 Secondary Energy Sources**

A cost comparison between A) - over sizing the PV generator and B) - adding a secondary 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 at latitudes above 40° where summer and winter solar irradiation levels are quite different, a secondary source can be considered for the purpose of reducing the system battery capacity, at the same time saving weight, equipment volume and building space. Portable generators have been used to minimise life cycle costs by including the charge during scheduled maintenance.

### **6.4 Solar Sizing Design 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.

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 sites where published data has been obtained with those at the installation site. Local cloud or mist conditions and local topography may considerably affect coastal sites by shading the solar array. Vegetation at land sites 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.

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

#### **6.4.1 Self-contained PV Energy Lights**

It is not possible to have the same light intensity using the same solar system throughout the world.

Consideration should be given to asking the supplier to state the operational life expectancy and expected reliability and performance under the specified design conditions over an identified time period, typically three to five years.

Users should specify their operational requirements as under low battery voltage conditions, the light may turn off completely or reduce its intensity pro rata with battery charging data.

Area specific solar data is required to properly size the solar PV system for a self contained light. The ability to deliver the required range taking account of vertical divergence and flash

character to the required operating standard depends on the specific data for the site. In addition, consideration should be given to the assumptions made for the battery autonomy requirements. Degradation in the performance of the battery should also be considered for the stated life span of the unit.

The installer of the lantern should also take into account the site topography to minimise shading of the solar array.

#### **6.4.2 PV Energy on Buoys**

Sizing the solar power system on a buoy is subject to greater variations than one on a fixed structure. Some programmes may include rough rules-of-thumb to account for buoy movement and alignment, however experience in the use of solar power systems on buoys is also important. When choosing a programme to use for solar system design, authorities should be aware of what rules are being applied by that programme.

#### **6.4.3 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.

The IALA Guidelines on Designing Solar Power Systems for Aids to Navigation (Dec. 2004) refer.

### **6.5 *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 – Annex 1 – Terminology - refers).

#### **6.5.1 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.

#### **6.5.2 Temperature Effects**

Note that effective battery capacity will be significantly reduced (by as much as 50%) by high (above 40°C) or low (below - 5°C) battery temperature. In hot or cold climates special precautions should 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. High temperature conditions will have an impact on life expectancy.

### **6.5.3 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 is a rule of thumb 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, nickel metal hydride and lithium ion batteries should be considered for the worst cases (very high latitude in the northern and southern hemispheres and very low temperature).
- Batteries with low self-discharge become important when the design requires a long autonomous period for the system.

### **6.5.4 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.

AGM and gelled electrolyte batteries are often used on buoys to prevent spillage of electrolyte. Consult with the manufacturer.

### **6.5.5 Advances in Technology**

Battery manufacturers or suppliers should be consulted during AtoN system design, as battery technology is continually evolving.

### **6.5.6 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.

### **6.5.7 Battery Maintenance**

IALA Guidelines on Battery Maintenance (latest edition) refers. It is important to 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 circumstances. Sealed batteries of all types have some form of a pressure vent and if overcharged 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.

### **6.5.8 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:

#### **6.5.8.1 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.

#### **6.5.8.2 Self-regulated PV Modules**

- Usually these are modules with only 32 solar cells or less for 12V systems, 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.

#### **6.5.8.3 Electronic Charge Regulator**

- Can be either series or parallel type to protect against overcharge or complete discharge.
- Lithium ion batteries require a specific type of regulator incorporated in the battery pack.
- The advantage of shunt regulation is low component count and low self-consumption.
- All regulators require some cooling.
- Prolongs the battery life and reduces the need for topping up.
- Ensures that the battery is operated within its designed operating specifications.
- With a series regulator there is only small energy dissipation.

- 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.

### **6.5.9 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.

The batteries should be pre-formed (charge cycled approximately three times) prior to installation for maximum battery capacity and life in accordance with the manufacturers recommendations.

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.

Maximum power tracking where the electronic regulator automatically maximises the charge for any level of insolation can be a useful feature.

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.

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

Nickel Metal Hydride batteries require voltage control using series regulators.

Lithium Ion batteries require special and complex charging control.

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.
- 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).
- The effects of stratification over long period of time should be considered.

### **6.5.10 Remote Monitoring of Battery Condition**

Primarily, for large PV installations with significant investment costs, as might be found at lighthouses or major beacons or at installations in high latitudes in both northern and southern hemispheres, 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.

### **6.5.11 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.

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. The PIV (peak inverse voltage) should be greater than twice the system open circuit voltage.

### **6.5.12 Shading (or bypass) Diodes**

Above 24V, diodes should be installed to prevent damage when parts of the array are partially shaded.

## ***6.6 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 should be weighed against the costs of maintenance (vehicle, tender, helicopter, and people).

It may be difficult to obtain exact replacement modules in the future as they may be of different dimensions. End users may wish to purchase some spares to cover life cycle management.

### **6.6.1 Practical Guide to Choice of Energy Systems**

Tables 2 and 3 are intended to assist in the selection of power systems for required types and sizes of loads, however these are only approximate indications.

## ***6.7 Installation of Modules***

### **6.7.1 Electrical Connections**

Some manufacturers supply their modules with waterproof junction boxes attached to the back. 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 AWG number equivalent to high csa (mm<sup>2</sup>) should be used to have reduced resistance and a sufficient mechanical strength. Cables should be suitable for UV and the marine environment. The conductors would be better protected by plating, e.g. tinned copper wire.

### **6.7.2 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.

### **6.7.3 Protection from Bird Fouling**

In some areas birds cause real problems by fouling modules. A great number of devices have been devised but none are 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 should be considered.

### **6.7.4 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 AtoN 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.

### **6.7.5 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 AtoNs, 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 in both the northern and southern hemispheres.

During winter months, at medium latitude ( $45^{\circ} \pm 5^{\circ}$ ) 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.

### **6.7.6 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.

Refer to the IALA Guideline on protection of Lighthouses and Aids to Navigation against Damage from Lightning, June 2000.

## ***6.8 Maintenance***

Maintenance of a PV power system at AtoN should, of course, be planned as part of a total maintenance programme for all components of the AtoN site. Minimum maintenance is required as part of life cycle costs. This is facilitated by initial investment and by selection of the correct systems.

### **6.8.1 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 output terminals], discoloration of the encapsulant, de-lamination, and bird fouling.
- Confirm load demand is within specified limits.
- Check 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.

### **6.8.2 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.

### **6.8.3 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.

Primarily for large installations 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.

The trend for buoys is for a period of between two to four years (and increasing) with the period being determined by other requirements, e.g. moorings.

## ***6.9 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 and shading 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 to avoid 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.

## **7 Other Technologies In The Area Of Aids To Navigation**

This section includes technologies that have not been fully tested to the reliability expected by IALA or technologies that are still under development and will be kept under review. The stated information about these technologies might not be up to date.

### **7.1 Seawater Battery**

In its present condition the technology needs to be improved before this type of battery can be recommended for AtoN systems.

### **7.2 Current and Tidal Turbines**

Currently under development.

### **7.3 Stirling Engine Generators**

This is an external combustion engine that is promising for use in applications requiring a combination of heat and electrical energy i.e. Lighthouses as part of a Hybrid Solar System. Output is typically 5kW of Heat and 0.7kW of electrical (DC) power for charging batteries.

#### **Advantages:**

- Less pollution than diesel internal combustion engine generators.

***Disadvantages:***

- Complex control system.
- Servicing is technically specialised.
- Diesel fuel has to be transported and stored.

***Comment:***

- Continuing development programs with alternative fuel sources.

## **7.4 Thermo Electric Generator**

***Advantages:***

- Simplification of thermopile (1 vs. many).
- Simple Venturi burner design (vs. catalytic).
- Low maintenance (10,000 hour schedule).
- High reliability.
- Low cost source power over long periods.
- Environmentally friendly.
- Hybrid Systems using TEG with any combination of photovoltaic and/or wind may offer opportunities previously considered unattractive.

***Disadvantages:***

- Low efficiency.
- Adequate source of fuel.

## **8 Life Cycle Management Considerations**

Covers from conception to disposal and is having an increasing impact on the design and selection of equipment and has also a direct link to the overall financial requirements.

Disposal of equipment containing hazardous materials is an increasingly important factor. Emphasis is being put on reworking reusing components to extend life and then the re-cycling of equipment in preference to disposal.

## 9 References

### 9.1 IALA Related Documents

- Recommendation for the notation of luminous intensity and range of light. November, 1966.
- Recommendation for a definition of the nominal daytime range of maritime signal lights intended for the guidance of shipping by day. April 1974.
- Recommendation for the colours of light signals on Aids to Navigation. December 1977.
- Recommendation on the determination of the luminous intensity of a marine Aid to Navigation light. December 1977.
- Recommendation for the calculation of the effective intensity of a rhythmic light. November 1980.
- Recommendation E-110, for the rhythmic characters of lights on Aids to Navigation. May 1998.
- Recommendation E-112, for leading lights. May 1998.
- Recommendation E-123, on the Photometry of Marine Aids-to-Navigation Signal Lights. June 2001.
- Recommendation A-126 on the use of AIS in Aids to Navigation. December 2003
- IALA practical notes on the application of solar power systems for Aids to Navigation. September 1993.
- Guidelines no. 1012 for the protection of lighthouses and Aids to Navigation against damage from lightning. December 2000.
- Guidelines no. 1011 on a standard method for defining and calculating the load profile of Aids to Navigation. December 1999.
- Guidelines no. 1025 on maintenance and operation of batteries. December 2001.
- Guidelines 1021 on new light sources and associated power supplies. December 2001 (revoked by IALA Guideline no. 1043 December 2004).
- Guidelines No. 1039 on Designing Solar Power Systems for Aids to Navigation (December 2004)

## 9.2 **Relevant IEC Standards**

### 9.2.1 **Battery related**

<b><u>Standard</u></b>	<b><u>Status</u></b>	<b><u>Title</u></b>
IEC 62060	Draft	Guide for the use of monitoring systems for lead-acid batteries.
IEC 61427	Issued	Secondary cells and batteries for solar photovoltaic energy systems - General requirements and methods of test.
IEC 60896	Draft	Stationary lead acid batteries - Part 21: Valve regulated types - Functional characteristics and method of test.

### 9.2.2 **Solar PV related**

<b><u>Standard</u></b>	<b><u>Status</u></b>	<b><u>Title</u></b>
IEC 62253	New work	Photovoltaic stand-alone systems - Design Qualification and Type Approval.
IEC 62111 Now renumbered as 62257 Parts 1- 10	Draft	General directive for the use of renewable energies (REN) in decentralised and rural electrification - Rules on the design and operation systems - Architecture of electrification system using PV modules.
IEC 62109	Draft	Electrical safety of static inverters and charge controllers used in photovoltaic power systems.
IEC 61427	Issued	Secondary cells and batteries for solar photovoltaic energy systems.
IEC 61683	Issued	Photovoltaic systems - power conditioners - procedure for measuring efficiency.
IEC 61836-2	New work	Specification for the use of renewable energies in rural decentralised electrification.

## Annex 1 - 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:**

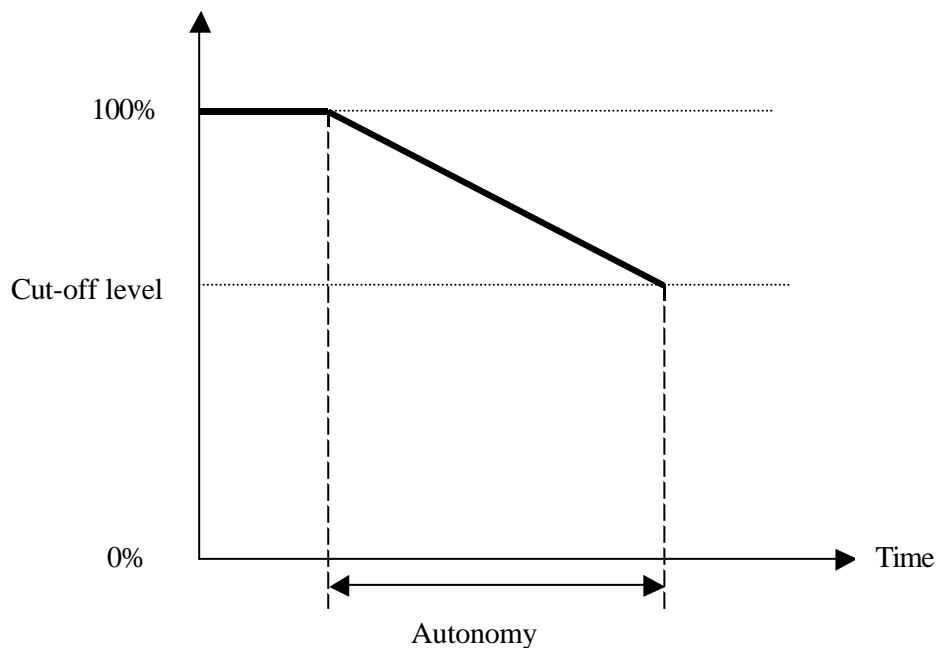
A mechanically integrated assembly of modules or panels together with support structure but exclusive of foundation, tracking, thermal control and other such components, to form a DC power producing unit.

### **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 should 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

$$FF = \frac{P_{\max}}{V_{oc} * I_{sc}}$$

**Irradiance:**

( $Wm\hat{I}^2$ ) radiant power incident upon unit area of surface.

**Irradiance, Direct ( $Wm\hat{I}^2$ ):**

The radiant power from the sun's disc and from a small circumsolar region of the sky within a subtended angle of  $5^\circ$  incident upon unit area.

**Irradiance, Diffuse: ( $Wm\hat{I}^2$ ):**

The total radiant power incident upon a unit area excluding the direct irradiance.

**Irradiation :**

Integration of irradiance over a specified period of time. ( $MJm\hat{I}^2$  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 (I<sub>sc</sub>):**

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<sup>2</sup>).

**Spectral response (absolute) (S<sub>abs</sub>):**

The short circuit current density generated by unit irradiance at a particular wavelength ( $\lambda$ ), plotted as a function of wavelength.

**Spectral response (relative) (S<sub>rel</sub>):**

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.

## **Annex 2 - Results of the Year 2000 Survey of the Use of PV Energy Systems by IALA Members**

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.

### **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 AtoNs and
- 44,044 fixed AtoNs.

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.

### **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 AtoNs and 30.6% of floating AtoNs were powered by solar PV systems.
- 12.6% of fixed AtoNs were powered from the public utilities supply.
- 3.3% of fixed AtoNs and 8.2% of floating AtoNs were powered by primary cells (not rechargeable) mainly in the countries operating floating AtoN above 60' latitude.
- 1.2% of fixed AtoNs and 2.3% of floating AtoNs were powered by gas (mainly acetylene).
- 1.2% of fixed AtoNs were powered by diesel generators.
- 0.1% of fixed AtoNs were powered by kerosene.
- 0.3% of fixed AtoNs and none of the floating AtoNs 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 1 %) of floating AtoN had hybrid sources mainly PV and wave, or PV and primary cells.

## 2.1 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:  $\bar{P}$  (P lamp x duty cycle) / total number of AtoN under consideration.

Average duty cycle:  $\bar{D}$  (duty cycle) / total number of AtoN under consideration

## 2.2 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

## 2.3 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 60° (sometimes horizontal)		