IALA GUIDELINE

G1067-3
ELECTRICAL ENERGY STORAGE FOR AtoN

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DOCUMENT REVISION

Revisions to this document are to be noted in the table prior to the issue of a revised document.

Date	Details	Approval
May 2009	1st issue	Council 45
December 2017	Entire document reviewed and updated following the realignment of the documentation to the IALA document structure. Updated to reflect information from the workshop on sustainable light and power for the next generation.	Council 65
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1. INTRODUCTION

1.1. SCOPE AND PURPOSE

Electrical energy storage devices are an essential part of the power systems, and must be properly designed, installed, operated and maintained if they are to deliver the appropriate level of availability.

This Guideline provides maintenance directives, operating criteria and safe handling guidance for energy storage devices commonly used in Marine Aids to Navigation (AtoN) applications.

While this document gives general recommendations, manufacturers may provide specific instructions for operation and maintenance of their specific equipment.

This Guideline is meant to assist users in properly selecting and maintaining energy storage systems used in Marine Aids to Navigation.

2. HOW TO USE THIS GUIDELINE

This document is part of a set of guidelines and needs to be read in conjunction with the following documents:

- IALA Guideline *G1067-0 Selection of Power Systems for AtoN and Associated Equipment*
- IALA Guideline *G1067-1 Total Electric Loads of AtoN*
- IALA Guideline *G1067-2 Power Sources*

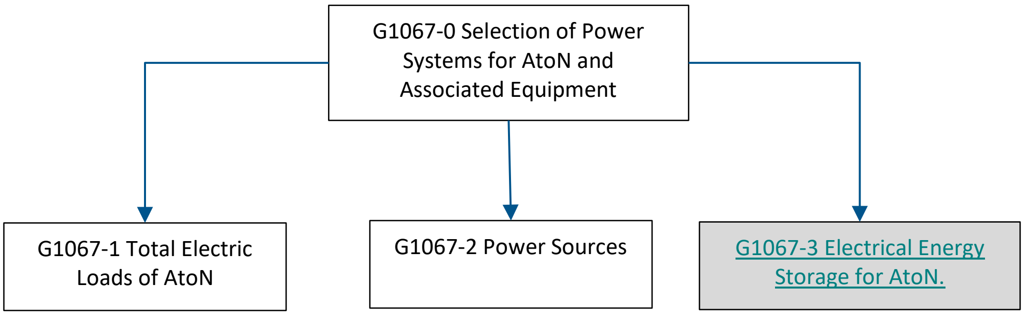

Figure 1 - Overview of guideline structure

3. TYPES OF BATTERY ENERGY STORAGE

The various types of battery energy storage systems in AtoN services are primary batteries (non-rechargeable) and secondary (rechargeable) batteries. The choice of battery type will be made at the design stage and should be appropriate for use considering local constraints and needs of the user. The following listings outline the advantages and disadvantages of the majority of battery types in general use.

NOTE The below is not an exhaustive list of battery types but covers the main types currently used in AtoN applications.

3.1. PRIMARY (NON-RECHARGEABLE) BATTERIES

- Air depolarized dry batteries
- Zinc Carbon batteries
- Sealed alkaline batteries
- Lithium batteries

3.2. SECONDARY (RECHARGEABLE) BATTERIES

The applications of the secondary batteries may fall into two main categories.

3.2.1. FIRST CATEGORY

Those applications in which the secondary battery is used or discharged essentially as a primary battery but recharged after use rather than being discarded. Secondary batteries are used in this manner for convenience, for cost savings (as they can be recharged rather than replaced), or for applications requiring power drains beyond the capability of primary batteries.

3.2.2. SECOND CATEGORY

Those applications in which the secondary battery is used as an energy-storage device, generally being electrically connected to and charged by an energy source and delivering its stored energy to the load on demand when the energy source is not available, or is inadequate to handle the load requirement.

- Lead-acid batteries:
  - Sealed (maintenance-free, valve-regulated) batteries
  - Flooded electrolyte batteries (wet battery type)
- Nickel-cadmium batteries:
  - Vented pocket-plate batteries
  - Vented sintered-plate batteries
  - Sealed batteries
- Nickel-metal hydride batteries
- Lithium batteries:
  - Lithium-ion batteries
  - Lithium-iron-phosphate batteries
  - Lithium polymer batteries

4. MAJOR ADVANTAGES AND DISADVANTAGES OF VARIOUS TYPES OF BATTERIES USED IN MARINE AtoN

4.1. PRIMARY BATTERY TYPES

This section covers the description of batteries designed especially for primary batteries use (primary energy source). It is important that over-current protection is considered on all primary battery banks.

4.1.1. AIR DEPOLARIZED DRY BATTERIES

4.1.1.1. Advantages

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

4.1.1.2. Disadvantages

- Air breathing is required; limiting installations to mostly shore based AtoN or buoys with carefully designed ventilation.
- Appropriate disposal is necessary.

4.1.2. ZINC CARBON

These are being superseded with alkaline types.

4.1.2.1. Advantages

- Cheap and reliable sealed types require no maintenance for stand-alone applications such as buoys, beacons and RACONs, but are increasingly unavailable in parts of the world.

4.1.2.2. Disadvantages

- Short shelf life
- Limitation in instantaneous output power
- Often not more than 20% load factor is available
- Poor low temperature service capacity

Figure 2 - Primary Cells

4.1.3. SEALED ALKALINE BATTERY

4.1.3.1. Advantages

- Longer life cycle to that of Zinc Carbon
- Very useful in operating buoy lights and other applications requiring sealed secure operation
- Good low temperature performance

4.1.3.2. Disadvantages

- High cost, generally low voltage per unit meaning multiple sets of these batteries are needed to make 12V systems

4.1.4. LITHIUM

4.1.4.1. Advantages

- Low weight and high-energy density
- Long shelf life

4.1.4.2. Disadvantages

- There is an explosion risk if incorrectly operated.
- Transportation restrictions
- High purchase cost

4.2. SECONDARY BATTERY TYPES

This section covers the description of rechargeable batteries that are used where a charging source is available. It is important that over-current protection is considered on all secondary battery banks.

4.2.1. FLOODED LEAD-ACID BATTERIES

4.2.1.1. Advantages

- Popular low cost battery – readily available
- Available in large quantities and in a variety of sizes, designs and capacities
- Good high discharge rate performance
- Reasonable storage life – can be stored in dry conditions
- Electrically efficient
- High cell voltage
- Good float charge service
- Easy state-of-charge indication (only wet electrolyte)
- Proven technology

4.2.1.2. Disadvantages

- Relatively low deep discharge cycle life
- Low specific energy – typically 30 – 40 Wh/kg
- Poor low- and high-temperature performance
- High self-discharge
- Long-term storage in a discharged condition can lead to electrode sulphation
- Hazardous contents (corrosive electrolyte)
- Need adequate ventilation to avoid explosive condition
- Hazardous and difficult to transport and install
- Stratification may occur with a low recharge rate
- Rapid unexpected failure

4.2.2. VALVE-REGULATED LEAD-ACID (VRLA) BATTERIES - ABSORBED GLASS MATT (AGM) AND GEL ELECTROLYTE

4.2.2.1. Advantages

- Maintenance-free (no requirement for topping up)
- Long life on float service
- Good high discharge rate performance
- Electrically efficient
- Popular low cost battery – readily available
- Available in large quantities and in a variety of sizes, designs and capacities
- Proven technology
- No gas venting in normal operation
- No spill risk
- AGM is preferred for colder climates

Figure 3 - Installation of Gel batteries in a signalling float

4.2.2.2. Disadvantages

- Long-term storage in a discharged condition can lead to electrode sulphation
- Relatively low energy density
- Hazardous contents (corrosive electrolyte)
- Need adequate ventilation to avoid explosive condition
- Poor low- and high- temperature performance
- Difficult to check capacity remaining
- Deep discharge can lead to battery failure
- Overcharge control required

4.2.3. VENTED (INDUSTRIAL) NICKEL-CADMIUM BATTERIES (POCKET PLATE)

4.2.3.1. Advantages

- Reliable and robust
- Long cycle life (more than 2,000 cycles, the total lifetime up to 25 years)
- Low self-discharge
- Can tolerate deep discharge
- Can tolerate high and low temperatures

- Excellent long-term storage (in any state of charge)
- High recharge rate

4.2.3.2. Disadvantages

- Need adequate ventilation to avoid explosive condition
- Low energy density
- Higher initial cost than lead-acid batteries
- Contains cadmium, which may increase cost of disposal depending on recycling facilities available
- Memory effect (voltage depression) if not periodically deep cycled
- Hazardous to transport

4.2.4. VENTED-SINTERED-PLATE NICKEL-CADMIUM BATTERIES

4.2.4.1. Advantages

- Flat discharge profile
- 50 % higher energy density than the pocket plate
- Superior high-rate and low-temperature performance
- Rugged, reliable, little maintenance required
- Excellent long-term storage in any state of charge over a very broad temperature range (-60 °C to +60 °C)
- Low self-discharge
- High cycle life
- Lifetime in excess of 20 years can be expected

4.2.4.2. Disadvantages

- Need adequate ventilation to avoid explosive condition
- Contains cadmium, which may increase cost of disposal depending on recycling facilities available.
- Hazardous to transport
- Low energy density
- Higher initial cost
- Memory effect (voltage depression) if not periodically deep cycled
- Overcharge control required
- Contains cadmium, which may increase cost of disposal depending on recycling facilities available.

4.2.5. SEALED NICKEL-CADMIUM BATTERIES

4.2.5.1. Advantages

- Cells are sealed
- Maintenance-free operation
- High cycle life
- Lifetime in excess of 20 years can be expected

- Good low-temperature and high discharge rate performance capability
- Long shelf life in any state of charge
- Rapid recharge capability
- Excellent reliability
- Rugged, resist rough handling

4.2.5.2. Disadvantages

- Needs adequate ventilation as hydrogen production can result in an explosion hazard
- Thermal runaway in improperly designed batteries or charging equipment
- Voltage depression in certain applications
- Difficult to recycle as the battery contains cadmium (hazardous material), which may increase cost of disposal depending on recycling facilities available
- Higher cost than sealed lead-acid battery
- Difficult to transport.

4.2.6. NICKEL-METAL HYDRIDE BATTERIES

4.2.6.1. Advantages

- Maintenance free
- Sealed battery
- Long life (expected in order of 15 years)
- High energy density relative to volume and weight
- No gas venting in normal operation
- High cycle life (about 1,200 cycles is typical, but depends on the depth of discharge)
- Wide operational temperature range (-20ºC to +60ºC is typical)

4.2.6.2. Disadvantages

- High cost
- Overcharge control required
- Risk of thermal runaway

4.2.7. LITHIUM-ION BATTERIES

4.2.7.1. Advantages

- Maintenance free
- Sealed battery
- Long life (expected in order of 20/25 years)
- Very high energy density relative to volume and weight
- No gas venting in normal operation
- High cycle life, but depends on the charging regime
- Low self-discharge

- High charging efficiency

4.2.7.2. Disadvantages

- High cost
- Complexity of battery integrated electronic management system
- Thermal runaway in improperly designed batteries or charging equipment
- Stringent transportation restrictions
- Must be stored in a partial charged state
- Degrades at high temperature above 55°C
- Battery destruction if charged below -5°C
- Hazard of explosion & fire

4.2.8. LITHIUM POLYMER

Lithium-polymer batteries are available and have similar characteristics to lithium-ion batteries but are more stable.

4.2.9. LITHIUM IRON PHOSPHATE

4.2.9.1. Advantages

- Maintenance free
- Sealed battery
- Long life (expected in order of 20/25 years)
- Very high energy density relative to volume and weight
- High cycle life, but depends on the charging regime
- Low self-discharge
- High charging efficiency
- Enhanced inherent safety compared to other lithium products

4.2.9.2. Disadvantages

- High cost
- Stringent transportation restrictions
- Degrades at high temperature above 55°C

5. OPERATIONAL CRITERIA FOR SECONDARY BATTERIES

This section specifies the operation criteria for secondary battery applications.

These battery systems can supply constant, variable or intermittent energy to the connected equipment (load) and can be charged by utility power, renewable energy sources and hybrid systems.

5.1. COMPUTING THE CAPACITY NEEDED

The required battery capacity can be determined by following Guideline *G1067-1 Total electrical loads for aids to navigation for AtoN solar systems*, IALA guideline IALA Guideline *G1039 Designing Solar Power Systems for Aids to Navigation* [4] and the solar sizing program, found on the IALA website, can be used to aid the calculation.

5.2. ELECTROLYTE STRATIFICATION

Electrolyte stratification may occur in flooded lead-acid batteries. In these batteries, electrolyte stratification can be avoided by electrolyte agitation or periodic boost charging whilst in service and in VRLA batteries by operating them according to the manufacturer's instructions.

5.3. TRANSPORTATION

Batteries are often operated in AtoN sites, with challenging or limited access. Any selected batteries should be designed to withstand mechanical stresses during normal transportation and rough handling. Suitable packing to protect the batteries must be used during transportation.

Some batteries may be transported dry and filled with electrolyte and charged in accordance with the manufacturer's recommendations on site.

When transporting any battery there may be restrictions or regulations that need to be complied with. Examples of these are dangerous goods by air, by road and marine transportation restrictions.

5.4. WEIGHT

Weight is an import consideration when selecting the type of battery to ensure suitable safe handling procedures are followed. Selection, design and placement of batteries in supporting structures need to consider the weight to ensure safe operation.

5.5. STORAGE

Manufacturers can provide recommendations for safe storage.

Some batteries may require periodic recharge in line with manufacturer's instruction.

A loss of capacity may result from exposure of a battery to high temperature and humidity during storage.

5.6. OPERATING TEMPERATURE

The temperature range during operation experienced by the battery will significantly affect battery life and is an important factor for the battery selection.

Batteries should be operated with the temperatures specified by the battery manufacturer. Operation of batteries outside these specified temperature ranges will have an adverse effect on the capacity and life expectancy and may prove hazardous.

5.7. PHYSICAL PROTECTION

Physical protection needs to be provided against consequences of adverse site conditions, for example, against effects of:

- Temperature gradient and extremes of temperature
- Exposure to direct sun light (UV radiation)
- Airborne dust or sand
- Explosive atmospheres

- High humidity and flood water
- Earthquakes
- Shock, spin, acceleration and vibration (particularly during transport, and light buoy applications)
- Severe mechanical abuse and rough handling

5.8. CAPACITY

The storage capacity is expressed in ampere-hours (Ah) and varies with the conditions of use (electrolyte temperature, discharge current and final voltage). Normally the rated capacity for 10 hours (C_{10}) and 5 hours (C_5) discharge, respectively, is published. The knowledge of the capacity for a 100 hours (C_{100}) discharge time is also required as these times are commonly used in PV applications.

5.9. CYCLE LIFE

The cycle life is the number of cycles obtainable from a cell or battery under specified conditions.

The cycle life is normally given for cycles with a fixed depth of discharge (DOD) and with the battery fully charged in each cycle. Batteries are normally characterized by the number of cycles that can be achieved before the capacity has declined to the value specified in the relevant standards (e.g., 80 % of the rated capacity at a specified temperature, typically 25°C).

In photovoltaic applications the battery will be exposed to a large number of shallow cycles but at a varying state of charge. The batteries should therefore comply with the requirements of the test described in *IEC 61427* [1], which is a simulation of the PV system operation. The manufacturer should specify the number of cycles the batteries can achieve before the capacity has declined to the value specified in the relevant standards (e.g., 80 % of the rated capacity).

5.10. DESIGN LIFE

The design life is often supplied by the manufacturer and should be suitable for the application and accessibility of the site. This is often a limiting factor when operated from a utility supply. The design life of the battery should be considered in the context of the overall system design life.

5.11. CHARGING PARAMETERS

To maintain optimum performance of a battery, it is essential that its charge is properly controlled. The method of controlling is specific to the battery type and this information is usually provided by the manufacturer. Failure to follow this will shorten the life and could prove hazardous. Excessive overcharge does not increase the energy stored in the battery and should be avoided as it can result in damage to the battery.

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

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

The charge control regime should take into account the battery temperature, particularly in high and low temperature applications. Users should refer to battery manufacturer specifications for guidance.

5.12. MONITORING OF BATTERY CONDITION

Monitoring and control of the battery parameters can be cost-effective, depending on risk. This can be locally or remotely, dependant on location. It allows battery condition to be checked, and remedial action taken as necessary. Monitoring will allow for the prediction of possible battery issues allowing action to be taken before these issues result in a failure. Some details on monitoring are available in IALA Guideline *G1008 Remote Control and Monitoring of Aids to Navigation* [5].

5.13. SELF DISCHARGE

Self-discharge of a battery used in a renewable application must be very low. The self-discharge figure should be stated by the manufacturer and should meet the requirements of the relevant battery standard. This needs to be accounted for when designing the system.

5.14. OVER DISCHARGE PROTECTION

Batteries should be protected against over discharge to avoid capacity loss or damage. This can be achieved by load reduction or disconnect that operates when the design maximum depth of discharge is exceeded.

The use of a load reduction or disconnect mechanism, is also recommended to prevent premature ageing of the battery and possible failure, which may result from excessive battery discharge in accordance with the manufacturers details.

5.15. 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.

Absorbed glass matt (AGM) and gelled electrolyte batteries are often used on buoys to prevent spillage of electrolyte. Consult with the manufacturer.

5.16. 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 ability to source the battery, costs of accessing the AtoN site, and by the ease of fast access in the event of a failure.

6. SAFE HANDLING OF ENERGY STORAGE SYSTEMS

Batteries are an integral part of any energy storage system used in AtoN and safe handling is one of the key considerations.

6.1. BATTERY SAFETY ISSUES

Large battery systems are a source of extremely high short circuit currents. Care must be exercised when installing and servicing any of the components in the power system to prevent shorting.

Some types of secondary batteries generate hydrogen gas during the charging process. Significant amounts of hydrogen gas are generated when the battery reaches full charge. Hydrogen gas ignites easily and produces an especially violent explosion. Care should be taken to avoid an explosive atmosphere and ensure all sources of ignition are controlled under both normal and fault operation. Often legislation dictates safety requirements for certain battery types. Manufacturers will help in providing the relevant battery specific safety information.

Some batteries contain hazardous chemical solutions that can be harmful to personnel and the environment.

When working with batteries, suitable personal protective equipment and appropriate tools need to be used as an effective way of minimising risk. Training and competency of personnel are also key issues.

6.2. INSTALLATION

Unless shipped dry, batteries should be installed as soon as possible after receipt. Otherwise, batteries should be stored indoors in a cool, dry area. All secondary batteries should receive a freshening charge immediately after installation.

Installation should preferably be in a clean, dry area and out of direct sunlight (to prevent individual cell heating and to protect against UV light). Exterior battery boxes should be constructed of an electrically insulating material, light coloured to prevent heating by the sun, and provide containment in the event of a cracked cell (wet batteries only). Interior battery racks, if used, should employ insulated trays or linings to isolate the cells from ground, and well secured to prevent tipping.

Install cell interconnections as per manufacturer’s instructions. Coat cell posts and interconnections with acid-free grease to prevent corrosion. Insulated interconnection covers are recommended to prevent accidental short circuits, but in order to be effective they should be designed so as not to impede routine servicing tasks.

6.3. VENTILATION

Lead-acid and nickel-cadmium batteries produce hydrogen and oxygen gas when charging. Secondary batteries that employ recombination features will only gas when the gassing rate exceeds the recombination rate. This generally occurs during overcharge. Batteries without recombination features will gas when they are fully charged and continue to receive a charge (float condition). The amount of hydrogen and oxygen evolved is not dependent on the type and size of battery (lead-acid or nickel-cadmium), but rather on the charging rate, number of cells and the length of time charge is applied. Hydrogen and oxygen are produced as a result of electrolysis of the water in the electrolyte. Hydrogen concentrations of up to 3% (by volume) are non-flammable, at 4-8% hydrogen will burn if exposed to an open flame or spark, and above 8% hydrogen will ignite explosively. Hydrogen can also be produced in battery pockets by reaction between residual water and dissimilar metals or corrosion of metals by spilled electrolyte.

Ventilation shall be provided in accordance with – *IEC 62485-2 Safety requirements for secondary batteries and battery installations - Part 2: Stationary batteries* [2].

Where possible natural ventilation should be used, if natural ventilation is unable to produce the necessary air changes, then mechanical exhaust ventilation can be employed.

Recombination caps are available for various battery types. These will reduce the amount of hydrogen vented by the battery, but battery compartment ventilation will still be required. Details of volumes of gas produced will be available from the battery manufacturer.

6.4. RECYCLING AND DISPOSAL

The laws and regulations, both national and international, governing the recycling and disposal of batteries are continually evolving. Batteries are considered hazardous waste. The heavy metals used in these batteries, when improperly disposed of, will damage the environment; the corrosive nature of battery electrolytes can also cause damage if released. While lithium batteries pose little pollution risk they must still be disposed of as hazardous waste because of their history of explosive venting if not fully discharged. Lead-acid and nickel-cadmium batteries are recyclable in most countries, although restrictions on nickel-cadmium recycling appear to be increasing, along with the associated costs. For further guidance on disposal see IALA Guideline *G1036 Environmental Management in Aids to Navigation*[3].

7. MAINTENANCE PRACTICES

7.1. GENERAL CONSIDERATIONS

In a correctly designed AtoN application, the battery may require minimal maintenance. However, it is good practice with a battery system to carry out an inspection of the battery system either at least once per year, or at the recommended interval to ensure that the charger, the battery, and the ancillary electronics are functioning correctly.

The basic requirements for the maintenance of a battery power system may fall into the following groups, which can be considered and optimized for any set of circumstances:

- Battery maintenance according to manufacturer’s requirements
- Requirements of the application and environment, including the type of AtoN, its intended mode of operation, charging method, environments
- Requirements of the user/operator including Installation site – environment and accessibility, maintenance philosophy, skill and training levels of maintenance staff.

7.2. INSPECTIONS

When an inspection is carried out, it is recommended that specific procedures should be adopted to ensure that the battery is maintained in a good state. The results of all inspections should be recorded, which can include the measured values as well as events such as mains power cuts, discharge tests, capacity tests, storage times and condition, topping updates etc.

Adequate battery records are invaluable aids in determining battery condition. An example of an inspection procedure is described in the following paragraphs.

7.2.1. INITIAL READINGS

The initial readings are those readings taken at the time the battery is placed in service. The following readings should be taken and recorded following a rest period on a fully charged battery with no load on the system:

- Battery terminal voltage and cell voltages if possible
- Cell electrolyte levels, where accessible
- Specific gravity reading of each cell corrected to 25 °C, where accessible
- Ambient temperature
- Charger voltages and current limit

It is important that these initial readings be recorded for future comparison.

7.2.2. MEASUREMENTS AND RECORDING

In general, all the measurements taken during the initial inspection should be continued for the life of the installation. The following additional measurements can be monitored and recorded.

- Cell temperatures whilst on charge should be uniform and the temperature differences between individual units should not exceed 3 °C
- Pilot-cell (if used) voltage, specific gravity, and electrolyte temperature (whenever possible)
- Use of de-ionised water

7.2.3. ELECTROLYTE LLVEL

Some battery types require periodic filling of lost water to maintain performance. Always observe the manufacturers recommendation in relation to electrolyte levels. Use only approved distilled or de-ionised water to refill the cells. Do not overfill the cells. It is therefore recommended that initially electrolyte levels should be monitored regularly to determine the frequency of refilling. There are automatic refill systems available for remote locations.

A reasonable consumption of water is the best indication that a battery is being operated under the correct conditions. Any marked change in the rate of water consumption should be investigated immediately.

Excessive consumption of water may indicate being charged at too high a voltage or too high a temperature. Negligible consumption of water, with batteries on continuous low current or float charge, could indicate undercharging.

Sealed maintenance-free batteries do not require water refills. Pressure valves are used for sealing and cannot be opened without destruction.

7.2.4. VISUAL CHECKS

General appearance and cleanliness of the battery and battery area (room, cabinet). Exclude any potential contamination and keep the battery housing, cells, vents, terminals and connectors clean, as dust and damp cause current leakage. Any spillage during maintenance should be wiped off with a clean cloth. The battery can be cleaned using fresh water or according to manufacturer’s recommendation. Some additional visual checks can include:

- Inspect for cracks and splits in battery cases or leakage of electrolyte.
- Look for evidence of corrosion at the connections.
- The connections and terminal screws should be corrosion-protected by coating with thin layer of acid free grease
- Check tightness of all bolted connections (torque specified by manufacturer).
- Loose bolts and bad connections can cause failure, high temperatures and even fire
- Condition of the ventilation system; verify that the ventilation ducts and filters operate correctly and allow continuous airflow throughout the battery room or cabinet.
- Check for evidence of current leakage to ground.
- Check integrity of battery support structure and enclosure.

7.3. CORRECTIVE ACTIONS – GENERAL

The following items are conditions that should be corrected at the time of inspection.

7.3.1. EQUALIZING CHARGE

The corrective action of an equalising charge to bring the cells to a uniform voltage and specific gravity levels, should be performed in accordance with the manufacturer's instructions. This is required whenever any of the following conditions are found.

- For wet lead acid cells, the specific gravity, corrected for temperature and electrolyte level, of an individual cell is more than 0.010 kg/l below the average, or all the cells drop by more than 0.010 kg/l from the average installation value at the time of inspection.
- The fully charged cell voltage is 0.1 V outside of the manufacturer's recommended end-of-charge cell voltage.

If these conditions are allowed to persist for extended periods, this can result in a reduction in battery life. This does not necessarily indicate a loss of capacity.

7.3.2. CELL REPLACEMENT

A faulty cell may be replaced by one in good condition of the same make, type, rating, approximate age and charged state. A new cell should not be installed in series with older cells except as a last resort.

7.3.3. STRATIFICATION OF THE ELECTROLYTE

The stratification of the electrolyte in large cells resulting in levels of varying concentration can limit charge acceptance, discharge output, and life unless controlled during the charging process. Two methods for stratification control are by deliberate gassing of the plates during overcharge at the finishing rate or by agitation of cell electrolyte by pumps (usually airlift pumps).

7.3.4. MEMORY EFFECT

The memory effect, describing a process which results in the temporary reduction of the capacity of a nickel-cadmium sintered cell following repetitive shallow charge/discharge cycles, is completely reversible by a maintenance cycle consisting of a thorough discharge followed by a full and complete charge/overcharge.

8. DEFINITIONS

The definitions of terms used in this Guideline can be found in the *International Dictionary of Marine Aids to Navigation* (IALA Dictionary) and were checked as correct at the time of going to print. Where conflict arises, the IALA Dictionary should be considered as the authoritative source of definitions used in IALA documents.

9. ABBREVIATIONS

AGM	Absorbed glass matt
Ah	Ampere hour(s)
AtoN	Marine Aids to Navigation
Cx	Capacity of a battery that has been completely discharged over a period of x hours
DOD	Depth of discharge
IEC	International Electrotechnical Commission
kg	Kilogram
kg/l	kilograms/litre (specific gravity)
PV	Photovoltaic
RACON	Radar beacon
UV	Ultraviolet

V	Volt(s)
VRLA	Valve-regulated lead-acid (battery)
Wh/kg	watt hours/kilogram
°C	degree(s) Celsius

10. REFERENCES

[1] International Electrotechnical Commission (IEC) (2013). Secondary cells and batteries for renewable energy storage – General requirements and methods of test – Part 1: Photovoltaic off-grid application, IEC 61427-1. IEC Geneva, Switzerland.

[2] International Electrotechnical Commission (IEC) (2010). Safety requirements for secondary batteries and battery installations - Part 2: Stationary batteries, IEC 62485-2. IEC Geneva, Switzerland.

[3] IALA Guideline G1036 Environmental Management in Aids to Navigation.

[4] IALA Guideline G1039 Designing Solar Power Systems for Aids to Navigation.

[5] IALA Guideline G1008 Remote Control and Monitoring of Aids to Navigation.