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**On**

**Power Sources**

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Table of Contents

[Document Revisions 2](#_Toc448313567)

[Table of Contents 3](#_Toc448313568)

[Index of Tables 5](#_Toc448313569)

[Power Sources 6](#_Toc448313570)

[1 Introduction 6](#_Toc448313571)

[1.1 Scope and purpose 6](#_Toc448313572)

[1.2 Practical Guide to Choice of Energy Systems 6](#_Toc448313573)

[2 How to use this guideline 6](#_Toc448313574)

[3 Alternating Current (AC) UTILITY POWER 6](#_Toc448313575)

[3.1 General 6](#_Toc448313576)

[3.2 Advantages 6](#_Toc448313577)

[3.3 Disadvantages 6](#_Toc448313578)

[4 PHOTOVOLTAIC POWER (PV) 7](#_Toc448313579)

[4.1 General 7](#_Toc448313580)

[4.2 Advantages 7](#_Toc448313581)

[4.3 Disadvantages 7](#_Toc448313582)

[4.4 Detailed information: 7](#_Toc448313583)

[5 Wind power 7](#_Toc448313584)

[5.1 General 7](#_Toc448313585)

[5.2 Advantages 7](#_Toc448313586)

[5.3 Disadvantages 8](#_Toc448313587)

[5.4 Detailed information 8](#_Toc448313588)

[6 Wave Activated Generator (WAG) 8](#_Toc448313589)

[6.1 General 8](#_Toc448313590)

[6.2 Advantages 8](#_Toc448313591)

[6.3 Disadvantages 8](#_Toc448313592)

[7 Fuel Cells 8](#_Toc448313593)

[7.1 General 8](#_Toc448313594)

[7.2 Advantages 9](#_Toc448313595)

[7.3 Disadvantages 9](#_Toc448313596)

[8 Diesel Generators 9](#_Toc448313597)

[8.1 General 9](#_Toc448313598)

[8.2 Advantages 9](#_Toc448313599)

[8.3 Disadvantages 9](#_Toc448313600)

[9 Petrol/Gas Engine Generators 10](#_Toc448313601)

[9.1 General 10](#_Toc448313602)

[9.2 Advantages 10](#_Toc448313603)

[9.3 Disadvantages 10](#_Toc448313604)

[10 Hybrid Power Systems 10](#_Toc448313625)

[10.1 General 10](#_Toc448313626)

[10.2 Advantages 10](#_Toc448313627)

[10.3 Disadvantages 10](#_Toc448313628)

[10.4 Comments 10](#_Toc448313629)

[10.5 Design considerations: 10](#_Toc448313630)

[11 Energy Source Selection 11](#_Toc448313631)

[11.1 Health, Safety and Environmental Considerations 11](#_Toc448313632)

[11.2 Energy Generation Profile 11](#_Toc448313633)

[11.3 Operational Restrictions 11](#_Toc448313634)

[12 Energy Regulation 11](#_Toc448313635)

[13 Lightning/surge Protection 11](#_Toc448313636)

[14 Installation 11](#_Toc448313637)

[14.1 General 11](#_Toc448313638)

[14.1.1 Electrical Connections 11](#_Toc448313639)

[14.2 Installation 12](#_Toc448313640)

[14.2.1 General 12](#_Toc448313641)

[14.2.2 Details for PV systems 12](#_Toc448313642)

[15 Maintenance 12](#_Toc448313643)

[15.1 Programmed Maintenance 13](#_Toc448313644)

[15.2 Frequency of Maintenance Visits 13](#_Toc448313645)

[15.3 Training of Maintenance Personnel 13](#_Toc448313646)

[16 Design Life 14](#_Toc448313647)

[17 References 14](#_Toc448313648)

[18 Acronyms 14](#_Toc448313649)

[ANNEX 1 PHOTOVOLTAIC POWER 15](#_Toc448313650)

[1 PV Module Technology 15](#_Toc448313651)

[1.1 Modular Design Considerations 15](#_Toc448313652)

[1.1.1 Example of a Modular Design Concept 15](#_Toc448313653)

[1.2 Solar Sizing Design Computer Programs 15](#_Toc448313654)

[1.2.1 PV Energy on Buoys 16](#_Toc448313655)

[1.3 Charge Regulation 16](#_Toc448313656)

[1.3.1 Self-regulated PV Modules 16](#_Toc448313657)

[1.3.2 Electronic Charge Regulator 17](#_Toc448313658)

[1.3.3 Shading (or bypass) Diodes 17](#_Toc448313659)

[1.4 Practical Considerations 17](#_Toc448313660)

[ANNEX 2 WIND GENERATION 18](#_Toc448313661)

[1 Power production 18](#_Toc448313662)

[1.1 Horizontal axis 18](#_Toc448313663)

[1.2 Vertical axis 18](#_Toc448313664)

[1.3 Particular considerations 18](#_Toc448313665)

[ANNEX 3 Generators 18](#_Toc448313666)

[ANNEX 4 Fuel Cells 18](#_Toc448313667)

[ANNEX 5 Mains 18](#_Toc448313668)

[ANNEX 6 Wave Generators 18](#_Toc448313669)

Index of Tables

[Table 1 Power sources combination possibilities 12](#_Toc225673198)

Power Sources

# Introduction

## Scope and purpose

This guideline replaces IALA Guideline 1044 on Renewable Energy Sources for Aids to Navigation (June 2005) and includes text from IALA Guideline 1042 on Power Sources for Aids to Navigation (December 2004), which it also replaces.

This guideline provides guidance on the design and selection of power sources. While this document gives general recommendations, product manufacturers may provide specific instructions for selection, operation and maintenance of equipment.

This guideline is meant to assist users to properly select and maintain power sources used in Marine Aids to Navigation systems.

## Practical Guide to Choice of Energy Systems

Table 1 of section IALA1067-0 Selection of Power Systems for Aids to Navigation and Associated Equipment is intended to assist in the selection of power systems for required types and sizes of loads, however these are only approximate indications.

# 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 1067-0 Selection of Power Systems for Aids to Navigation and Associated Equipment

IALA Guideline 1067-1 Total Electric Loads of AtoN

IALA Guideline 1067-3 Electrical Energy Storage for AtoN

# Alternating Current (AC) UTILITY POWER

## General

The availability of AC utility power at or near the site should be the first consideration. Where AC power is available, it should be the preferred source of energy. Backup systems should be installed in order to prevent AtoN failure in case of power outage.

## Advantages

* Load on the system is not critical;
* Low capital and running costs;
* Low maintenance.

## Disadvantages

* Reliance on external bodies;
* Possible unreliability of the AC power supply;
* Requirement for a back-up system that will need periodic maintenance.

# PHOTOVOLTAIC POWER (PV)

## General

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 capacity may be possible and vice versa.

An AtoN PV power system, in its simplest form, consists of a PV module and a secondary battery. However, the application of a charge regulator is highly recommended. 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.

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.

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.

## Detailed information:

For detailed information on photovoltaic systems see ‎ANNEX 1.

# Wind power

## General

Wind energy is a renewable source of energy that can be considered in order to power Aids to Navigation. 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. Wind generators are now available in vertical and horizontal axis generators.

## Advantages

* Easy to install;
* Can be part of a hybrid system;
* Variable power production capacities;
* Alternate source of power where low insolation prevents use of solar PV generation;
* Renewable energy source with associated cost savings.

## Disadvantages

* Technology is still under development;
* High maintenance requirements;
* Moving and rotating parts (safety);
* Subject to damage under local weather conditions, e.g. wind turbulence, freezing rain, typhoon;
* Might produce high noise pollution;
* Moving parts can be dangerous to fauna;
* Might have to be stopped during storm;
* Minimum wind speed required to start power production;
* Can be destroyed by vibrations in the supporting structure;
* Permission may be required for siting of the wind turbine;

## Detailed information

For detailed information on wind powered turbines, see ‎ANNEX 2.

# Wave Activated Generator (WAG)

## General

Wave activated generators are used on tail-tube buoys and light vessels. It is usually used as part of a hybrid system such as 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 may be inconvenient to handle;
* High capital cost;
* High maintenance cost - typically installations need to be serviced at yearly intervals;
* Limited availability – single source;
* Flora and fauna might limit the use of some types of WAGs.

# Fuel Cells

## General

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.

There are currently two types of fuel cells available on the market relevant to AtoN.

* Proton Exchange Membrane (PEM);
* The PEM is using gaseous hydrogen as direct fuel and can be used on medium and major fixed lights in remote areas;
* Direct Methanol Fuel Cell;
* This technology is using a mixture of methanol and water as fuel. Currently, the technology can produce power from 100 Watts to 5kW.

## Advantages

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

## Disadvantages

* Refuelling issues;
* Fuel safety and transportation issues;
* Stack lifetime is limited;
* Low temperature performance for some types;
* Capital cost.

# Diesel Generators

## General

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

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.

## 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;
* Regular maintenance required;
* Produces noise and atmospheric pollution;
* Regular refueling required;
* Cost of fuel transportation;
* Unattended service interval is short, typically 4 – 6 months;
* Fuel storage environmental risk has to be addressed at each site.

# Petrol/Gas Engine Generators

## General

Generally these power systems are used in a manner similar to the diesel generator systems described in the previous section. For these reasons petrol engine generators are not recommended for fixed installations.

## Advantages

* For the advantages, refer to section ‎8.2.

## Disadvantages

* Refer to the section ‎8.3;
* Fuel storage and transport safety implications;
* Less durable than diesel engine generators;
* Additional and more frequent service requirements.

# Hybrid Power Systems

## General

If one type of system (e.g. PV) is not sufficient to recharge the batteries, then the addition of another type of power source can be required (hybrid system).

The advantages of Hybrid systems lies in the mix of sources chosen matched against the need to reliably supply an AtoN power system. This can be achieved by combining different sources of power like PV modules, wind generators, or even diesel generators together to provide sufficient capacity to power the AtoN or recharge the energy storage devices.

## Advantages

* Ability to reduce the capacity of the energy storage system;
* More reliable than when power is provided by a single source.

## Disadvantages

* More complex system;
* Capital cost.

## Comments

A cost comparison between over sizing a PV generator and 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 W) 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 recharge during scheduled maintenance.

## Design considerations:

* Selection of Energy Storage solution;
* Energy storage must be sized to accept the peak current output from multiple sources concurrently;
* Selection of multiple input - hybrid solutions;
* Consideration to the mix of technologies. Ideally select devices of different types i.e. Passive and mechanical;
* Selection of a regulation system;
* Due consideration should be given to the mixing of regulators and the parallel connection of the outputs, i.e. Diode protection.

1. Power sources combination possibilities

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Fuel cell | Generator | Solar | Wind | Wave | Utility power |  |
| Fuel Cell |  | 0 | ++ | ++ | + | ++ |  |
| Generator | 0 |  | ++ | ++ | 0 | ++ |  |
| Solar | ++ | ++ |  | ++ | ++ | + |  |
| Wind | ++ | ++ | ++ |  | 0 | + |  |
| Wave | + | 0 | ++ | 0 |  | 0 |  |
| Utility power | ++ | ++ | + | + | 0 |  |  |
| Primary cell | 0 | 0 | ++ | + | 0 | + |  |

**Key to table:**

**++ - Preferred**

**+ - Recommended**

**0 - Not Recommended**

# Energy Source Selection

## Health, Safety and Environmental Considerations

## Energy Generation Profile

## Operational Restrictions

Think ventilation for generators, load management, etc.

# Energy Regulation

# Lightning/surge Protection

To protect a power system against destructive electrical surges such as lightning strikes, lightning protection should be considered. IALA Guideline 1012 on Protection of Lighthouses and AtoN against Damage from Lightning, June 2000, refer.

Over-voltage arrester devices should be used to increase the protection of the system.

# Installation

## General

### Electrical Connections

Cables with a low AWG number equivalent to high cross section area (csa)(mm2) should be used to have a 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.

In PV systems, 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.

## Installation

### General

Prevention against galvanic corrosion between dissimilar metals (frame/structure) using insulators or stand-offs is recommended. Devices (special screws or nuts, welded pieces, etc.) to dissuade thieves from removing equipment are recommended, as well as a notice board indicating the importance of the installation for maritime safety.

For PV systems, care should be taken at installation to see that the mounting hardware does not stress the module.

Also, 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.

### Details for PV systems

#### Protection from Bird Fouling

In some areas birds cause real problems by fouling modules. A great number of devices have been designed 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 in some cases, imply over sizing. The hazards presented to servicing personnel by metal bird spikes should be considered.

#### Mechanical Protection

Protection to reduce the effect of wave impact, storms, vandalism, theft, and buoy-handling, is generally required. Vertical mounting of the modules on a floating AtoN reduces the vulnerability of the modules but affects the performance of the solar panel.

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

#### 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 can also 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 (45º ± 5 º) 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.

# Maintenance

Maintenance of a power system at an 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.

## Programmed Maintenance

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

* Inspect all power sources components for corrosion (especially at the inter-cell connections and at the output terminals). For PV systems, inspect for cracks or discoloration of the encapsulant, de-lamination in the borders by ice effects or 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.;
* 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.

## 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 where applicable.

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.

## Training of Maintenance Personnel

A power 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.

# Design Life

# References

# Acronyms

1. PHOTOVOLTAIC POWER

# 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.

## 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.

### Example of a Modular Design Concept

The Australian Maritime Safety Authority has implemented a concept of a standardised solar PV powered generator (module + battery + charge regulator) that is installed in multiples.

The advantages of this system are:

* The standardisation of equipment;
* Easy stock keeping;
* Enhanced reliability;
* Smaller components simplifying transportation and handling;
* Reduces the scope of training for personnel.

One disadvantage is:

* Higher capital cost.

## Solar Sizing Design Computer Programs

Computer programs are available for calculating solar sizing. These programs take into consideration all or some of the following:

* Insolation data;
* Land and sea reflection coefficients;
* Temperature variations;
* PV array tilt angle;
* PV panel orientation;
* PV module efficiencies;
* Battery efficiencies (recharge characteristics and lifetime capacity loss);
* Battery self-discharge;
* Electrical load profile.

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.

IALA program on Designing Solar Power Systems for Aids to Navigation (Dec. 2004) is available to all IALA members. The Software calculation Microsoft Excel program provides an iterative method of designing a solar power system for fixed or floating AtoN installations. To obtain the Microsoft Excel program, including password and manual please contact IALA Secretariat via e-mail: [iala-aism@wanadoo.fr](mailto:iala-aism@wanadoo.fr).

Some authorities have their own in-house solar sizing programmes that could be made available to IALA members and some PV modules manufacturers might also provide computer program for system sizing.

### 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.

## 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 two possibilities for the charge regime:

### 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 10 ampere per 100 amp-hours capacity (C/10 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 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.

### Electronic Charge Regulator

* Can be either series or parallel type to protect against overcharge or complete discharge;
* 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;
* Lithium ion batteries require a specific type of regulator incorporated in the battery pack;
* 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;

### Shading (or bypass) Diodes

Above 12V, bypass diodes should be installed to prevent damage when parts of the array are partially shaded.

## Practical Considerations

It should be noted that PV modules 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 30 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.

1. WIND GENERATION

# Power production

## Horizontal axis

Based on 4m/s average wind speed, the power output (Watt Hour) versus Swept Area is approximately 75-100 kWh per square metre per year (kWh/m2/y). These numbers are based on information available and would need to be confirmed by the wind turbine manufacturer.

For example:

For a swept area of 2 m2 energy generated equals 2\*100 kWh = 200 kWh per turbine per year.

## Vertical axis

For small scale turbines and Based on 4m/s average wind speed, the power output (Watt Hour) versus Swept Area is approximately 240 kWh per square metre per year (kWh/m2/y).

For large scale turbines and Based on 4m/s average wind speed, the power output (Watt Hour) versus Swept Area is approximately 700 kWh per square metre per year (kWh/m2/y).

These numbers are based on information available and would need to be confirmed by the wind turbine manufacturer.

## Particular considerations

When selecting wind power-generators the following should be taken in to consideration:

* Operational and Environmental conditions;
* Reliability of the equipment;
* Environmental impact (noise, flora and fauna, visual impact, etc.);
* Maintenance requirements.

1. Generators

What do we cover in these annexes?

1. Fuel Cells
2. Mains
3. Wave Generators