IEC TS 62257-7-2

Edition 1.0 2022-03

TECHNICAL SPECIFICATION

colour inside

Recommendations for renewable energy and hybrid systems for rural electrification – Part 7-2: Generator set – Off-grid wind turbines

IEC TS 62257-7-2:2022-03(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.180 ISBN 978-2-8322-1087-2

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RECOMMENDATIONS FOR RENEWABLE ENERGY AND HYBRID SYSTEMS FOR RURAL ELECTRIFICATION –

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IEC TS 62257-7-2 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
82/1956/DTS	82/1995/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 62257 series, published under the general title, *Recommendations for renewable energy and hybrid systems for rural electrification* can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

The IEC 62257 series of publications intends to provide to different players involved in rural electrification projects (such as project implementers, project contractors, project supervisors, installers, etc.) documents for the setting-up of renewable energy and hybrid systems with AC voltage below 500 V, DC voltage below 750 V and power below 100 kW.

These publications provide recommendations for:

- choosing the right system for the right place;
- designing the system;
- operating and maintaining the system.

These publications are focused only on rural electrification concentrated in, but not specific to, developing countries. They are not considered as all-inclusive of rural electrification. The publications try to promote the use of renewable energies in rural electrification. They do not deal with clean mechanism developments at this time (CO2 emission, carbon credit, etc.). Further developments in this field could be introduced in future steps.

This consistent set of publications is best considered as a whole, with different parts corresponding to items for the safety and sustainability of systems at the lowest possible life-cycle cost. One of the main objectives of the series is to provide the minimum sufficient requirements relevant to the field of application, i.e. for small renewable energy and hybrid off-grid systems.

The purpose of this document is to provide guidance for the deployment of small wind turbines (a wind turbine with a rotor swept area smaller than or equal to 200 m^2, see IEC 61400-2: 2013) used in off-grid hybrid power system in rural electrification.

This document is a general introduction followed by more specific documents dedicated to the generation technologies which are the most currently used in rural electrification projects.

RECOMMENDATIONS FOR RENEWABLE ENERGY AND HYBRID SYSTEMS FOR RURAL ELECTRIFICATION –

Part 7-2: Generator set – Off-grid wind turbines

1 Scope

This document applies to all small wind turbines (SWTs) with a swept area smaller than or equal to 200 m^2, and designed for supplying electrical power to isolated sites used in systems as described in IEC TS 62257-2.

This document is not an exhaustive resource for the design, installation, operation or maintenance of small wind turbines and wind power systems, but is more focused on recommendations to provide strategies on selection and criteria which may affect the use of a small wind power system (SWPS) in a rural electrification project.

Only the hybrid collective electrification system (microgrid, isolated microgrid) including SWT(s) is considered in this document. SWT in an isolated microgrid can be a single wind turbine or multiple wind turbines. Isolated microgrid using only wind power generation is not discussed in this document. General functional configuration of SWT(s) in an off-grid hybrid power system is shown in Figure 1.

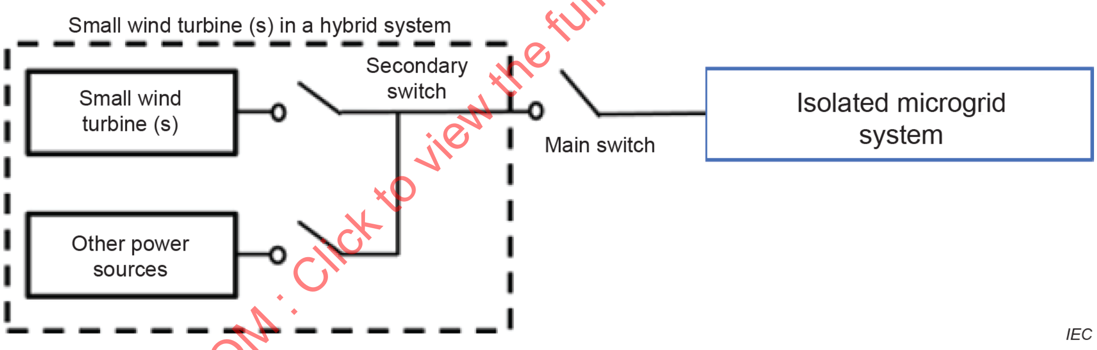


Figure 1 – General functional configuration of SWT(s) in an off-grid hybrid power system

The aim of this document is to provide users with the appropriate levels of reliability and safety of the equipment during its estimated service lifespan.

It describes the minimum safety requirements and does not claim to be an exhaustive instruction manual or design specification.

Compliance with this document does not exempt any person, organization, or corporation from the responsibility to comply with all other relevant regulations.

This document gives recommendations for the single SWT with a swept area smaller than or equal to 200 m^2, or multiple SWTs with other power sources of total capacity up to 100 kW in an off-grid hybrid power system.

The design life of a good quality modern wind turbine is 20 years. The real lifetime of a SWT is subjected to quite extreme loads throughout its life. This mostly depends on its designed structure and reliability of moving parts, because the power in the wind increases with the cube of the speed.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60038:2009, *IEC standard voltages*
IEC 60038:2009/AMD1:2021

IEC 60287 (all parts), *Electric cables – Calculation of the current rating*

IEC 60721-2-1:2013, *Classification of environmental conditions – Part 2-1: Environmental conditions appearing in nature – Temperature and humidity*

IEC 61140, *Protection against electric shock – Common aspects for installation and equipment*

IEC 61400-2:2013, *Wind turbines – Part 2: Small wind turbines*

IEC 61400-12-1, *Wind energy generation systems – Part 12-1: Power performance measurements of electricity producing wind turbines*

IEC TS 62257-2, *Recommendations for renewable energy and hybrid systems for rural electrification – Part 2: From requirements to a range of electrification systems*

IEC TS 62257-4, *Recommendations for renewable energy and hybrid systems for rural electrification – Part 4: System selection and design*

IEC TS 62257-5, *Recommendations for renewable energy and hybrid systems for rural electrification – Part 5: Protection against electrical hazards*

IEC TS 62257-6, *Recommendations for renewable energy and hybrid systems for rural electrification – Part 6: Acceptance, operation, maintenance and replacement*

IEC TS 62257-9-1, *Recommendations for renewable energy and hybrid systems for rural electrification – Part 9-1: Integrated systems – Micropower systems*

IEC TS 62257-9-2, *Recommendations for renewable energy and hybrid systems for rural electrification – Part 9-2: Integrated systems – Microgrids*

ISO 3864-1:2011, *Graphical symbols – Safety colours and safety signs – Part 1: Design principles for safety signs and safety markings*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/

- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
Annual Energy Production
AEP
calculated total energy that would be produced during a one-year period at an average wind speed of 5,0 m/s at hub height, assuming a Rayleigh wind speed distribution, 100 % availability, and the power curve derived from IEC 61400-12-1

SEE: 3.28.

3.2
annual average
mean value of a set of measured data of sufficient size and duration to serve as an estimate of the expected value of the quantity

3.3
annual average wind speed
V_{ave}
wind speed averaged according to the definition of annual average

3.4
brake
device capable of reducing the rotor speed or stopping rotation of a wind turbine system

3.5
collective electrification system
<isolated microgrid>
micro-power plant and micro-grid that supplies electricity to multiple consumption points using a single or multiple energy resource points

3.6
consumer label
label for the benefit of consumers consisting of two parts: the label itself, and a test summary report made available by a web site

3.7
control system
sub-system that receives information about the condition of the wind turbine system and/or its environment and adjusts the turbine in order to maintain it within its operating limits

3.8
start-up wind speed
wind speed at which the rotor first begins to turn after being at rest once spinning, wind turbine rotors can coast to lower wind speeds than those necessary to start the rotor revolving

3.9
cut-in wind speed
Vin
lowest mean hub height wind speed bin value at which the wind turbine system produces a net positive power output. The turbine does not produce power between start up wind speed and cut in wind speed.

3.10
cut-out wind speed
Vout
highest mean wind speed at hub height at which the wind turbine system is designed to produce power

3.11
downwind
in the main direction of wind flow

3.12
emergency shutdown
rapid shutdown of the wind turbine system triggered by a protection system or by manual intervention

3.13
external condition
factor affecting the operation of a wind turbine system including the environmental conditions (temperature, snow, ice, etc.) and the electrical network conditions that are not part of the wind turbine system

3.14
extreme wind speed
highest average wind speed, averaged over t seconds, that is likely to be experienced within a specified time period (recurrence period) of T years

3.15
fail-safe
design property of an item which prevents its failures from resulting in critical faults

3.16
hybrid power system
HPS
power system including generators from different technologies

3.17
horizontal axis wind turbine
HAWT
type of wind turbine in which the axis of the rotor's rotation is nominally parallel to the horizontal ground surface

3.18
hub
fixture for attaching the blades or blade assembly to the rotor shaft of a wind turbine system

3.19
hub height
height of the geometric center of the swept area of the wind turbine rotor above the terrain surface

3.20
mean wind speed
statistical mean of the instantaneous value of the wind speed averaged over a given time period which can vary from a few seconds to 1 year

Note 1 to entry: Though wind speed varies over a continuum, measurements used to develop power curves group power measurements into separate discrete registers or bins, for wind speed in m/s, typically 0,5m/s wide. The 5 m/s bin, for example, would represent winds from 4,75 to 5,25 m/s.

3.21
nacelle
housing which contains the drivetrain and other elements on top of a horizontal axis wind turbine tower

3.22
noise label
defined graphical and textual representation of the acoustic noise data pertaining to a small wind turbine system

3.23
overspeed control
action of a control system, or part of such system, which prevents excessive rotor speed

3.24
power form and voltage
physical characteristics which describe the form in which power produced by the wind turbine system is made deliverable to the load (e.g. 230 V AC, 50 Hz, 1 ph; or e.g. 48 V DC)

3.25
protection system
system which ensures that a wind turbine generator system remains within the design limits

3.26
rated power
maximum continuous electrical output power which a wind turbine system is designed to achieve at the connection facilities under normal operation

Note 1 to entry: The rated power of SWT is its output at 11 m/s at standard sea-level condition.

Rated power of SWT varies roughly proportionally to the swept area of the rotor. Blade design and technology developments are therefore one of the keys to increasing wind turbine capacity output. By doubling the rotor diameter, the swept area and therefore power output is increased by a factor of four.

3.27
rated wind speed
wind speed at which a wind turbine system's rated power is achieved. The distribution depends on one adjustable parameter – the scale parameter, which controls the average wind speed.

3.28
maximum design wind speed
highest allowable wind speed for turbine operations

Note 1 to entry: It is expressed in m/s.

3.29
swept area
projected area perpendicular to the wind direction that a rotor will describe during one complete rotation

Note 1 to entry: It is expressed in m^2.

3.30
Rayleigh distribution
probability distribution function often used for wind speeds

3.31
reference annual energy
calculated total energy that would be produced during a one-year period at an average wind speed of 5,0 m/s at hub height, assuming a Rayleigh wind speed distribution, 100 % availability, and the power curve derived from IEC 61400-12-1 (where it is referred to as Annual Energy Production (AEP))

Note 1 to entry: The AEP from IEC 61400-12-1 is either the "AEP-measured" or the "AEP-extrapolated", and is either "sea-level normalised" or "site-specific".

Note 2 to entry: In this document reference annual energy is AEP-measured and sea-level normalised.

Note 3 to entry: The reference annual energy is defined for the purposes of comparing wind turbine systems.

3.32
reference wind speed
V_{ref}
basic parameter for wind speed used for defining SWT classes

Note 1 to entry: Other design related climatic parameters are derived from the reference wind speed and other basic SWT class parameters.

Note 2 to entry: A turbine designed for a SWT class with a reference wind speed, V_{ref} , is designed to withstand climates for which the extreme 10 min average wind speed with a recurrence period of 50 years at turbine hub height is lower than or equal to V_{ref}.

3.33
resonance
phenomenon appearing in an oscillating system, in which the period of a forced oscillation is very close to that of free oscillation

3.34
rotor centre
geometric centre of the wind turbine rotor

3.35
rotor speed
rotational speed of a wind turbine rotor about its axis

3.36
scheduled maintenance
preventive maintenance carried out in accordance with an established time schedule

3.37
Small Wind Power System
SWPS
includes the wind turbine itself including support structures, the turbine controller, the charge controller / inverter (if required), wiring and disconnects, the installation and operation manual(s) and other documentation

3.38
Small Wind Turbine
SWT
wind turbine with a rotor swept area smaller than or equal to 200 m^2 (IEC 61400-2)

3.39
swept area
projected area perpendicular to the wind direction that a rotor will describe during one complete rotation

3.40
turbulence intensity
ratio of the wind speed standard deviation to the mean wind speed, determined from the same set of measured data samples of wind speed, and taken over a specified period of time

3.41
upwind
in the direction opposite to the main direction of wind flow

3.42
Vertical Axis Wind Turbine
VAWT
wind turbine system whose rotor axis is substantially perpendicular to the wind flow

3.43
Weibull distribution
probability distribution function often used for wind speeds

3.44
wind speed distribution
probability distribution function, used to describe the distribution of wind speeds over an extended period of time

3.45
wind shear
variation of wind speed across a plane perpendicular to the wind direction

3.46
wind speed

velocity of air at a specified point in space wind profile

3.47
wind profile
wind shear law mathematical expression for assumed wind speed variation with height above ground

Note 1 to entry: Commonly used profiles are the logarithmic profile (1) or the power law profile (2).

$$V_{(Z)} = V_{(Zr)} \times \frac{\ln(Z/Z0)}{\ln(Zr/Z0)} \tag{1}$$

$$V_{(Z)} = V_{(Zr)} \times \left(\frac{Z}{Zr}\right)^{\alpha} \tag{2}$$

where

$V_{(z)}$ is the wind speed at height z;

z is the height above ground;

z_r is a reference height above ground used for fitting the profile;

z_0 is the roughness length;

α is the wind shear (or power law) exponent.

3.48
yaw mechanism
yaw system is the component responsible for the orientation of the wind turbine rotor towards the wind

4 Symbols and abbreviated terms

4.1 Abbreviated terms

AEP annual energy production

EHS extra high strength

HAWT horizontal axis wind turbine

HPS hybrid power system

O&M operation and maintenance

QC quality control

RPM revolution(s) per minute

SWPS small wind power system

SWT small wind turbines

VAWT vertical-Axis wind turbine

VOM Volt-Ohm-Milliammeter, another name for a multimeter

WT wind turbines

4.2 Symbols

C_p power coefficient, a measure of wind turbine efficiency

D diameter of rotor

H_0 reference height

H height

K_i capacity descent factor

P rated capacity of an electronic component at normal conditions

P_i equivalent capacity at high elevation

V voltage

V_0 measured wind speed at the height H_0

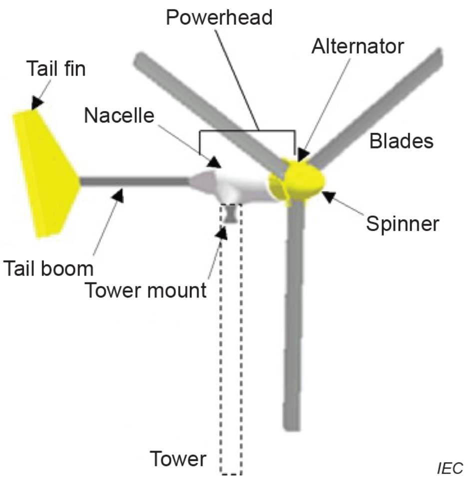
α wind shear exponent

5 Wind turbine (WT)

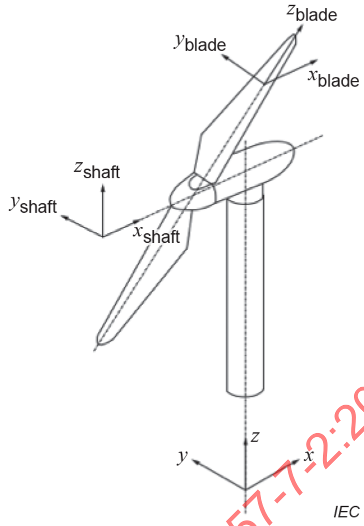
5.1 Types of wind turbines

5.1.1 Horizontal axis wind turbine (HAWT)

HAWT mainly consists of the following parts: rotor (blades), generator, speed regulating mechanism, direction regulating mechanism (yaw system), brake mechanism and tower. Normally HAWT has three blades, but can also have two blades or multiple blades. Typically a small HAWT uses a tail vane assembly for its direction regulating mechanism, while for a large HAWT, a transmission device consisting of a sensor element and a servo motor is used. Figure 2a) is tail vane direction regulating type, or called passive yaw regulation type, which is widely used in small wind turbines; while Figure 2b) is electrical transmission device direction regulating type, or called active yaw regulating type, which is used for all large wind turbines. Figure 3 shows examples of rotors with different number of blades. This document applies to designs with any number of blades.

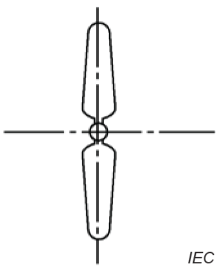


a) Passive yaw control regulation type

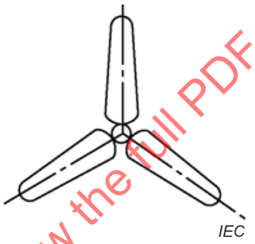


b) Example of two bladed wind turbine with active yaw system type

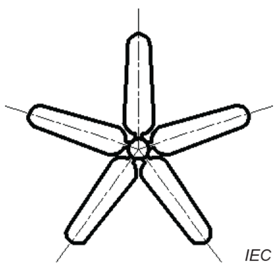
Figure 2 – Example of wind turbine with active yaw system



Two blades



Three blades



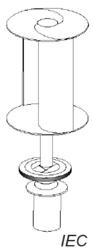
Multiple blades

Figure 3 – Rotors with different number of blades of a HAWT

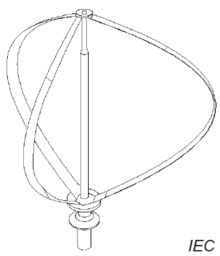
5.1.2 Vertical axis wind turbine (VAWT)

A vertical-axis wind turbine is a type of wind turbine where the main rotor shaft is set transverse to the wind while the main components are located at the base of the turbine.

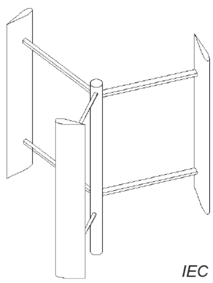
VAWT mainly consists of the following parts: rotor (blades), generator, control system, inverter, and tower. There are two types of VAWT: lift type and drag type. Figure 4 shows four typical designs sign diagrams that are classified according to the blade pattern, a is the lift type, b, c, and d, are drag type. This document applies to designs with any of these blade patterns.



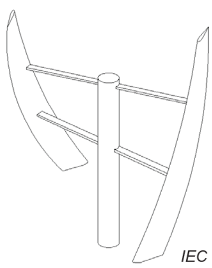
a) Savonius VAWT



b) Darrieus VAWT



c) Giromill-H-VAWT



d) Helical H-VAWT

Figure 4 – Four typical VAWTs

5.1.3 SWT classes

According to IEC 61400-2:2013, 6.2, SWTs are classified by V_{ref}, V_{ave}, I_{15}, and a, where:

a) V_{ref} is the reference wind speed, V_{ave} is the wind speed averaged according to the definition of annual average, the values apply at the hub height, and;

b) I_{15} is the dimensional characteristic value of the turbulence intensity at 15 m/s, where 0,18 is the minimum value that shall be used;

c) a is the dimensionless slope parameter to be used in standard deviation.

The user shall select the right SWT in the hybrid power system based upon local conditions, which includes V_{ref}, V_{ave}, I_{15} and a.

The external conditions to be considered in design are dependent on the intended site or site type for a SWT installation. SWT classes are defined in terms of wind speed and turbulence parameters. The values of wind speed and turbulence parameters are intended to represent the characteristic values of many different sites and do not give a precise representation of any specific site. The goal is to achieve SWT classification with clearly varying robustness governed by the wind. Table 1 specifies the basic parameters, which define the SWT classes. Class II wind turbines are the most common and those turbines will work in most places around the world. The design values for the SWT class S shall be chosen by the designer and specified in the design documentation.

Table 1 – Basic parameters for SWT classes

SWT Class		I	II	III	IV	S
V_{ref}	(m/s)	50	42,5	37,5	30	Values to be specified by the designer
V_{ave}	(m/s)	10	8,5	7,5	6	
I_{15}	(-)	0,18	0,18	0,18	0,18	
a	(-)	2	2	2	2	

5.2 General characteristics of SWT

5.2.1 Basic technical characteristics

a) Performance

Start-up wind speed (m/s).

Cut-in wind speed (m/s) V_{in}.

Rated wind speed (m/s).

Cut-out wind speed (m/s) V_{out}.

Maximum design wind speed (m/s).

Rated power (kW).

Rotor speed (rpm).

b) Mechanical

Type of SWT (HAWT/VAWT, number of blades, upwind/downwind).

Swept area (m^2).

Power and speed regulation mechanism (pitch control, furling, etc.).

Over speed protection (pitch control, furling, electric stall, tip brakes, etc.).

Mass (kg).

Operating temperature range (°C).

c) Electrical

Generator type (permanent magnet generator (PMG), excitation generator).

Output form and voltage (V).

Output control system.

For additional explanation of terms, refer to Clause 3.

Two examples of main characteristics of an off-grid wind turbine are given in Annex A, one for HAWT and another for VAWT.

5.2.2 Most important technical characteristics

5.2.2.1 General

The following four characteristics are essential to describe the characteristics of a SWT.

5.2.2.2 Annual Energy Production (AEP)

AEP is the estimated annual energy production assuming an annual average wind speed for example 5 m/s or 6 m/s, when comparing the AEP of different turbines make sure that assumed annual average wind speed is the same. A Rayleigh wind speed distribution, sea-level air density and 100 % availability. The amount of energy a SWT will produce is primarily a function of the rotor swept area.

The fundamental of the wind power is described as the following formula:

$$P=\frac{1}{2}\rho A V^3 C_p \quad (3)$$

where,

P is the power generated by the wind turbine;

ρ is air density, 1,225 kg/m^3, at standard condition, sea level, 15 ºC;

A is the swept area of the rotor. To HAWT, $A=\pi R^2$, R is the radius of the rotor of a HAWT. Wind power is proportional to the area or square of the radius of the rotor, regardless of the number of blades. To VAWT, where H = height and D = diameter of rotor:

H-type area = $H\times D$

Savonius area = $H\times D$

Darrieus area = 0,65 $H\times D$;

V is the instantaneous wind speed (m/s), not average wind speed. Wind power is proportional to the cubic of instantaneous wind speed;

C_p is the power coefficient, a measure of wind turbine efficiency.

As wind speed increases, the amount of available energy increases following a cubic function. Therefore capacity factors rise rapidly as the wind speed increases. There is a significant incentive to site the SWT in areas of lower turbulence and higher average wind speeds to maximize performance.

Measure the power curve and follow IEC 61400-12-1 to calculate the AEP.

Actual power production of a SWT will vary depending on site condition.

5.2.2.3 Rated sound level

The sound level that will not be exceeded 95 % of the time, assuming an annual average wind speed of 5 m/s, a Rayleigh wind speed distribution, sea-level air density, 100 % availability and an observer location 60 m from the rotor center.

5.2.2.4 Power curve

The power curve of a wind turbine is a graph that indicates how large the electrical power output will be for the turbine at different wind speeds. Power curves made available by the manufacturers help in estimating the wind energy potential in a candidate site. Accurate models of power curve serve as an important tool in wind power estimation. The designer can use power curve of the selected SWT and local distribution of wind speed to estimate the selected SWT performance at the site, if a measured power curve is provided it should be measured in accordance with a standard like IEC 61400-12-1.

5.3 Working conditions of SWT

SWTs designed to standard classes are evaluated for operation and faults under normal environmental working conditions which are:

a) Normal operation ambient temperature range: -10 ºC to + 40 ºC.

b) Relative humidity: ≤ 95 %.

c) Maximum altitude: ≤ 1 000 m. The applied capacity of a SWT shall be reduced per the real attitude of the site.

d) Turbulence: I_{15}≤ 0,18.

e) Solar radiation intensity of 1 000 W/m^{2}.

f) Air density of 1,225 kg/m^{3}.

g) Atmospheric content equivalent to that of a non-polluted inland atmosphere (see IEC 60721-2-1).

SWTs designed to standard classes are evaluated for operation and some faults under extreme environmental conditions which can include:

Temperatures of -20 °C to +50 °C, sand and blowing dust, corrosive environment including marine, lightning, earthquakes, and icing. Environmental conditions and their values shall be stated in design documentation and a wind turbine certified to a higher windspeed (e.g. SWT Class I instead of Class II) should be considered.

6 Off-grid Small Wind Power Systems (SWPS)

6.1 General

An off-grid small wind power system consists of SWT, tower, charging controller, brake, power storage, and DC/AC inverter. It may be used together with other power generators, such as PV or a diesel genset to form a hybrid power system.

6.2 Major components in SWPS

6.2.1 SWT

The SWT in a SWPS can be single or multiple turbines; and can be HAWT or VAWT. The layout of multiple SWTs on a site shall be carefully designed so as to avoid mutual interference.

A shorter blade wind turbine should be considered in the higher wind speed environment.

6.2.2 Tower

6.2.2.1 Basic requirements

The tower is designed to match the specific load and thrust of a particular SWT. The proper tower shall be selected for system design. The tower provided by the SWT manufacturer is typically the most suitable one.

Any customer-made tower shall follow the load and mechanical assembly information and requirements provided by the SWT manufacturer. The tower shall be designed by certified engineers, including the rooftop SWT. For turbines with a swept area of less than or equal to 2 m^2 the manufacturer shall supply all information needed by the user to select a suitable support structure for safe turbine operation. This shall include but is not limited to:

- details on the mechanical turbine/tower connection;
- details on the electrical turbine/tower connection;
- minimum blade/tower clearance;
- maximum allowable tower top deflection; and
- maximum tower top loads (stating whether a safety factor has been included, and its magnitude);
- a sample support structure design.

For turbines with a swept area of more than 2 m^2, it is recommended that the above information be supplied. For these turbines the information required by 6.2.2.2 shall be provided including drawings of a sample foundation stating assumed soil conditions, operating loads, and access loads.

Not just the weight of the SWT, but also the wind loads acting on the tower need to be carefully considered. Vibration and resonance also need be considered in the tower design. The design life of the tower shall not be less than the design life of the turbine.

The minimum tower height is determined by the site specific “neighbors”, such as the trees, residential houses, etc. Site assessment is the examination of a specific site’s orientation to the prevailing wind and an assessment of the impact of obstacles surrounding it radially. Develop a list of obstacles that are a distance less than 20 times their height from the proposed turbine location. The recommended approach for ground-mounted towers is to make sure that the lowest point of the rotor-swept area is higher than twice the height of the tallest obstacle within the distance of 20 times within the distance of 20 times the obstacle height. A higher tower will increase the power output of a SWT and reduce the impact of turbulence due to rough surface. Except for micro- and mini-turbines, the suggested tower height shall not be lower than 18 m for an open field. Expected changes to nearby obstacles (e.g., tree growth) shall be taken into consideration, and the tower height shall be determined for the expected life of the system.

Tower materials and coatings shall meet the requirements of the local environmental conditions (e.g., corrosive conditions such as salt mist).

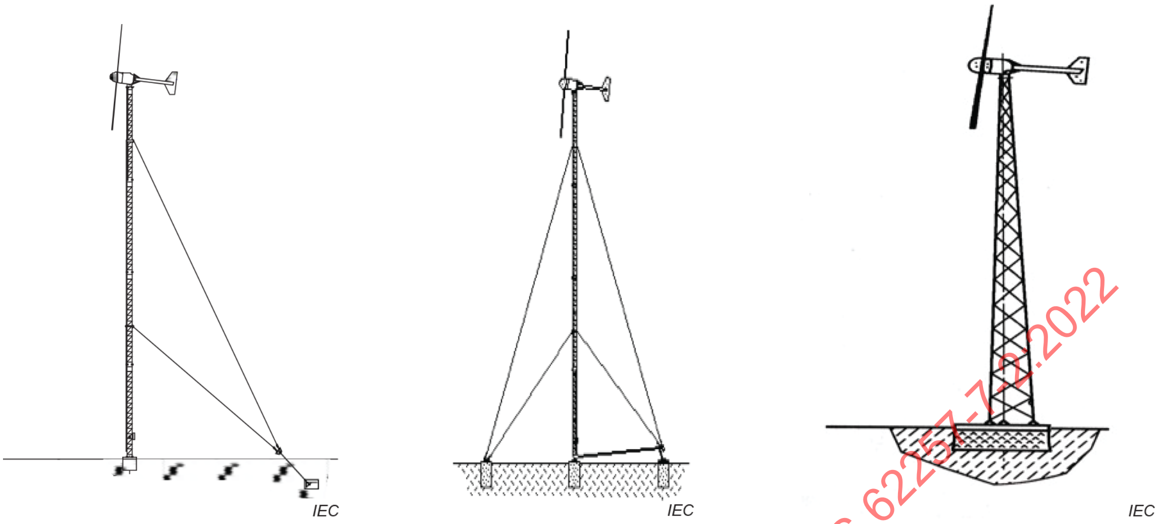
The tower should be selected to avoid the corrosion of salt mist and dust.

6.2.2.2 Tower types for off-grid SWPS

There are a variety of towers available for SWTs. The most common tower types are: guyed-wire tower, tilt-up tower and free-stand tower, as shown in Figure 5a), b), and c), but this document applies for other types as well. Each type of tower may have different structures, such as tubular, lattice, monopole, or cantilevered tubular, etc.

Tower stability and rigidness is designed by the SWT manufacturer to meet the stable and dynamic requirements of SWT performance. Selecting the tower associated with the selected

SWT from the manufacturer is safer. Ease of transportation, installation and later turbine maintenance on site are the most important considerations when selecting towers.



a) Guyed-wire tower b) Tilt-up tower c) Free-stand tower

Figure 5 – Variety of tower options

6.2.3 Controller

The wind turbine controller serves several functions which may include start-up and shut-down of the rotor, engaging the electrical generating system and load, or dump-load, release the parking brake at the correct time, monitor the rotor speed or the output voltage and current to meet the designed charging requirements, and creating a fault condition that causes turbine to stop if some parameters are not within typical operation conditions. It may also have an over speed control feature. The controller may also monitor the system performance data and have data acquisition features.

When used in a SWPS the controller shall be designed for that application and have some method for power control that is compatible with control of the power system. For instance, it could have communications capability that allows a power system controller to stop the SWT or reduce its power output to prevent overcharging the storage or causing overvoltage. Or it could have voltage limiting functions that protect the system. It is the responsibility of the system designer to ensure that the control functions of the SWT are compatible with the power system design and controls.

6.2.4 Brake

A braking system is required on small wind systems to control the rotor in abnormal conditions, such as loss of load, failure of a control system component, or maintenance. The operation of brakes can be classified as three operation conditions: Normal, normal stopping and emergency. Brakes can be grouped into three basic types: mechanical brakes, dynamic brakes, and aerodynamic brakes.

The protection system shall be designed to be fail-safe.

There shall be a manual shutdown button/switch/lever/etc., and shutdown procedures.

A safe method for shutdown of the SWT before performing inspections, service or maintenance, shall be provided by the SWT manufacturer.

6.2.5 Inverter

There are two types of inverters: DC input and AC input inverter. The type of selecting inverter is determined by the system bus type.

The capacity of the inverter should be calculated and determined by the load types, capacity and time of the electrical appliances in the system. Inductive loads shall be carefully separated from resistive loads and calculate the required capacity shall be ≥ 5~7 times of the capacity of these inductive loads.

The rated output capacity of the inverter should be greater than 3 to 5 times of the peak capacity of the system. The actual rated output capacity shall be assessed based upon the analysis of the system load simultaneous situation.

6.2.6 Storage system

Battery bank is the most common power storage system in off-grid renewable energy power system. Batteries used to store power from renewable energy sources shall be reliable, durable, and safe.

The series voltage of the battery shall be matched with the output voltage of the wind generator unit, and the output voltage of the solar cell module if the system is a hybrid one.

Battery capacity is jointly determined by the daily power consumption, set continuous cloudy days, the longest period of days without wind and the technical characteristics of the battery, such as self-discharge rate, charge/discharge efficiency and discharge depth factors.

The battery shall avoid being over-charged or over-discharged.

6.2.7 Dump load

The system should be equipped with dump load(s) if the selected SWT requires them to avoid turbine over speed and over-charging of the battery. The torque and thermal capacity of the dump load shall be sufficient to stop the rotor under any condition including conditions where the dump load is already hot from regulating rpm, power, or voltage. The dump load has to be installed outside to prevent fire due to over hot.

6.3 Design Procedure of SWPS

6.3.1 General

IEC TS 62257-4 shall be referred for the design of a SWPS.

For achieving better SWPS performance, the design of SWPS or a hybrid power system including wind component usually follows the following steps:

a) Local renewable energy (i.e., wind) resource assessment;

b) Local site assessment, including transportation condition assessment;

c) Determine the capacity of SWPS;

d) Select SWT(s).

6.3.2 Wind resource assessment

Project site wind resource assessment is critical to a SWPS or hybrid power system which includes SWTs. For cost-effectiveness, most wind resource assessments use available wind maps or wind speed information from the nearby sources such as similar SWPS, weather stations, airports or any kind of agencies or businesses that collect local weather information.

Be sure to know at what height these wind data are collected, then use wind shear property to adjust the wind speed data to hub height:

$$v=v_0\{H/H_0\} \quad (4)$$

where

v is the wind speed at height H,

v_0 is the measured wind speed at the height H_0, and,

α is the wind shear exponent.

The wind shear exponent will vary depending on atmospheric conditions and the terrain or roughness of the ground, it may vary from 0,14 to 0,6. For other information, see Annex B, Table B.1.

6.3.3 Site assessment

6.3.3.1 General assessment

A site visit is very important before designing the SWPS or hybrid power system. Road condition for transportation shall be evaluated. The site should be assessed before wind power system installation. The foundation construction should be designed according to the site land condition.

The obstacles on site, the potential turbulence and its impacts on SWT's performance shall be carefully evaluated. Use roughness and obstacles to estimate the turbulence intensity of a site.

For siting, understanding the prevailing wind direction(s) is as important as understanding the wind speed. The best place to put a SWT at the site is upwind of all obstacles towards the prevailing wind directions.

6.3.3.2 Foundation

For turbines with a rotor swept area greater than 2 m^2, the manufacturer shall specify the foundation requirements including layout of the foundation, location of guy wires with minimum and maximum guy location recommendations, and guy wire installation requirements as applicable. For turbines with a rotor swept area greater than 2 m ^{2} the manufacturer shall design a sample foundation system for normal soil conditions and design loads.

6.3.4 Determine the capacity of the SWPS

The turbine should be suitable for the external conditions of the site (extreme wind speed, humidity, temperature range).

6.3.5 Select SWT

The turbine should be suitable for the external conditions of the site (extreme wind speed, humidity, temperature range).

6.4 Configuration of SWPS

6.4.1 General

6.4.1.1 Basic configuration

Generally, the SWPS or hybrid power system can be connected with AC bus or DC bus, as shown in Figure 6 and Figure 7, or a combination of AC bus and DC bus. The designer can choose different configurations based on actual requirements.

The power generation equipment, such as SWTs, photovoltaic arrays or diesel engines can be added or reduced according to system design requirements.

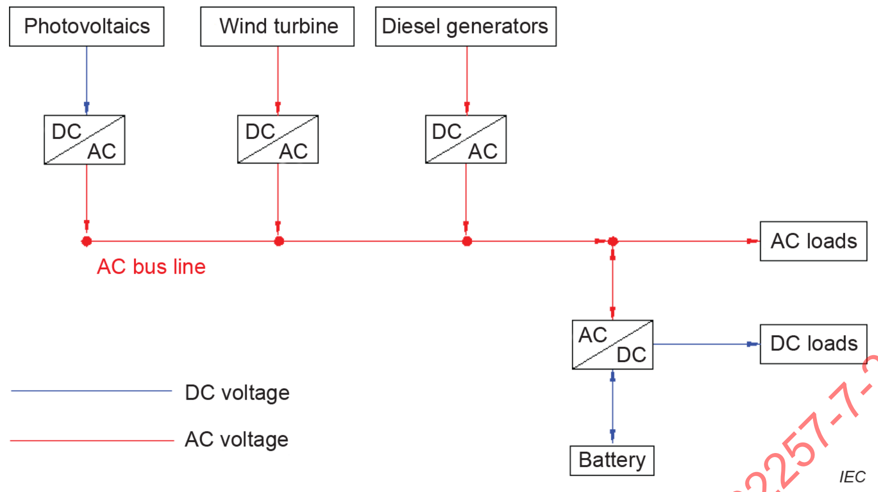


Figure 6 – AC bus system

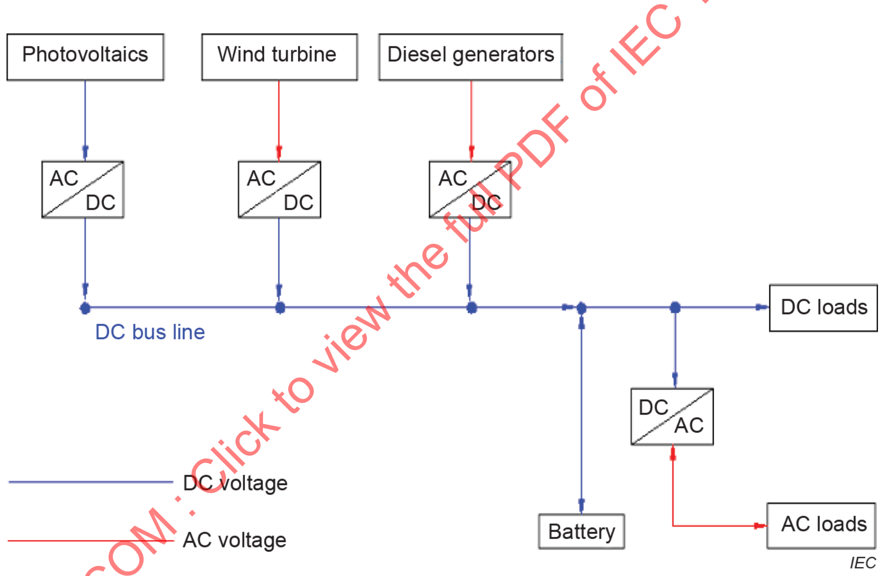


Figure 7 – DC bus system

6.4.1.2 Basic parameters of the system

a) Rated DC voltage

Rated DC voltages of the selected SWT will be determined by the entire system design and other equipment and cell technology. The rated DC voltage of the system should be chosen from Table 2. Refer to IEC 60038, standard voltages may vary as shown in Table 2, but the SWT shall be compatible with the selected system voltage.

The rated 750 V DC voltage of the systems should be chosen from Table 3.

Table 2 – Equipment having a nominal voltage below 750 V DC

Nominal values	
Preferred V	Supplementary V
-	2,4
-	3
-	4
-	4,5
-	5-
6	7.5
--	9
12	-
-	15
24	-
--	30
36	-
-	40
48	-
60	-
72	-
-	80
96	-
110	-
-	125
220	-
-	250
440	-
-	600

NOTE 1 Because the voltage of the primary and secondary cells is below 2,4 V, and the choice of the type of cell to be used in various applications will be based on properties other than the voltage, these values are not included in the table. The relevant IEC technical committees may specify types of cells and related voltages for specific applications.

NOTE 2 It is recognized that for technical and economic reasons, additional voltages may be required for certain specific fields of application.

Table 3 – Equipment having a nominal voltage below 750 V DC

DC nominal	
Preferred V	Supplementary V
-	2,4
-	3
-	4
-	4,5
-	5-
6	7.5
--	9
12	-
-	15
24	-
--	30
36	-
-	40
48	-
60	-
72	-
-	80
96	-
110	-
-	125
220	-
-	250
440	-
-	600

NOTE 1 Because the voltage of the primary and secondary cells is below 2,4 V, and the choice of the type of cell to be used in various applications will be based on properties other than the voltage, these values are not included in the table. The relevant IEC technical committees may specify types of cells and related voltages for specific applications.

NOTE 2 It is recognized that for technical and economic reasons, additional voltages may be required for certain specific fields of application.

b) Rated AC voltage, frequency and waveform

The rated AC voltage and frequency of the system should be selected in Table 4. The waveform is sine wave. Local voltage and frequency standards should be followed to allow locally available appliances and equipment to be utilized.

Table 4 – AC systems having a nominal voltage between 100 V and 1 000 V inclusive and related equipment

Three-phase four-wire or three-wire systems		Single-phase three-wire systems
Nominal voltage V		**Nominal voltage** V
50 Hz	**60 Hz**	**60 Hz**
–	120/208	120/240[d]
230[c]	240[c]	–
230/400[a]	230/400[a]	–
–	277/480	–
–	480	–
–	347/600	–
–	600	–
400/690[b]	–	–
1 000	–	–

[a] The value of 230/400 V is the result of the evolution of 220/380 V and 240/415 V systems which has been completed in Europe and many other countries. However, 220/380 V and 240/415 V systems still exist.

[b] The value of 400/690 V is the result of the evolution of 380/660 V systems which has been completed in Europe and many other countries. However, 380/660 V systems still exist.

[c] The value of 200 V or 220 V is also used in some countries.

[d] The values of 100/200 V are also used in some countries on 50 Hz or 60 Hz systems.

6.4.2 Layout SWT(s) on site

To meet a certain power generation capacity demand, the designer can either choose a single SWT, or multiple SWTs that have the combined capacity to meet the demand. Use of multiple SWTs versus one larger turbine may have the following advantages:

- More flexible system sizing.
- Increase the overall reliability – if one turbine is down due to maintenance/failure, there is still some power available.

The disadvantage of using multiple SWTs are the increased land usage compared to a single SWT, the wake impacts shall be evaluated, and the capital investment will usually be higher.

To layout multiple SWTs on a site, prevailing wind direction shall be well recognized and SWTs shall not be laid out in a line parallel to the prevailing wind direction. For horizontal spacing, 7 to 10 times the rotor diameter may be used if the turbines are downwind of each other in the prevailing wind direction, or 3 to 5 times if perpendicular to the prevailing wind direction. A minimum set-back distance between the wind turbine and the nearest building should be maintained as follows, height of the tower + one blade length + 5 m.

7 Selection of SWPS

7.1 General

SWT(s) shall be selected based upon the power demand of the SWPS, or the power demand (load profile) of the wind portion of a hybrid power system (HPS) after optimization of the configuration.

7.2 Selection criteria

7.2.1 General factors in selection of SWT

Based upon the designed SWPS or HPS, the following factors are most important to be considered:

- Size (rated capacity at rated wind speed),
- Rotor diameter,
- Tower-top weight,
- Certification or label (if available),
- Rated power (at 11 m/s),
- Peak power (kW at voltage),
- Estimated energy production based upon site conditions,
- rpm at rated power,
- Over speed control,
- Cost,
- Years in business of the manufacturer,
- Years model in production,
- Warranty, and after-sale service.

7.2.2 Rule of thumb

a) Turbine choices

In choosing a wind turbine consider the match between the electricity demanded by local loads and the SWT's production. Pay attention to the time match of the production and loads. For instance, seasonal, monthly and even diurnal patterns will affect the best selection of SWT, other generation, storage and load management approaches.

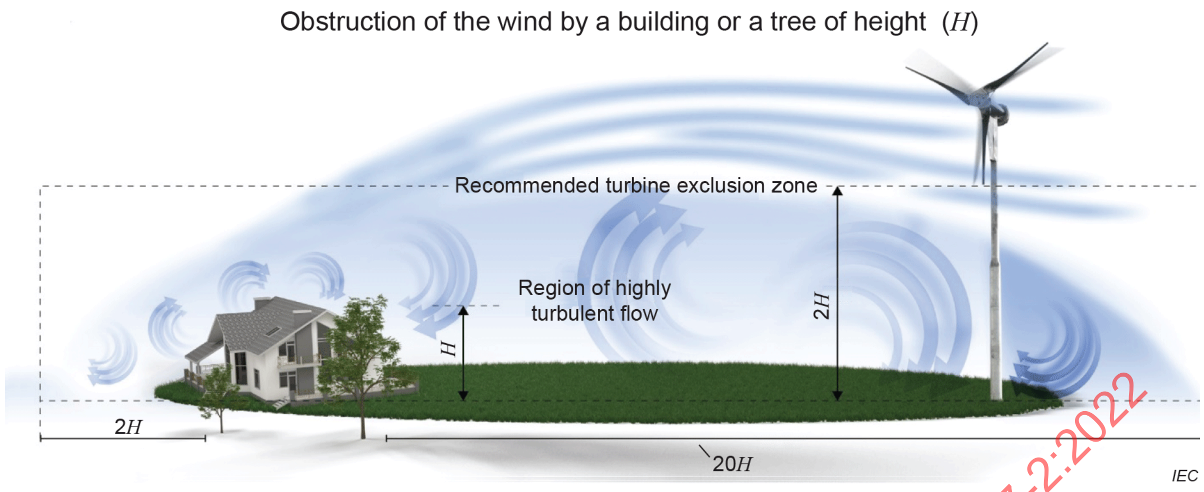
Swept area is a good comparative measure to approximate wind power production for turbines of a similar type.

b) Turbine size

The “rotor” is the collector area. More collector means more wind energy collection. Swept area is a good comparative measure to approximate wind power production for turbines of a similar type.

7.2.3 Wind turbine height

Generally, in order to reduce the turbulence and increase wind speed at the hub height. SWTs should be on a tall enough tower to have the lowest part of the rotor at least 2 times the height of any obstacle within 20 times the obstacle height upwind of the turbine. SWTs should be located at the height that the lowest part of the rotor is at least 10 m above any obstacle within a 100 m radius. A taller tower is always the best investment in a wind energy system, refer to Figure 8.



SOURCE: NREL, Josh Bauer, reproduced with the permission of the author.

Figure 8 – Obstruction of the wind by a building or a tree

7.2.4 Turbulence

Turbulence decreases performance and increases loads thereby increasing wear and shortening life of a SWT. SWTs should be sited to minimize exposure to turbulence as far as possible while maximizing exposure to the wind.

Carefully locating a wind turbine on a site will minimize the impacts of turbulence.

I_{15} is used in IEC61400-2, but practice shows that I_5 or I_{10} may be better to understand the inference of turbulence to the SWT's performance on the site (I_{15} average turbulence intensity at 15m/s).

7.3 Design of a microgrid or Isolated Microgrid with SWT

7.3.1 Meet national rural grid standards

The designed microgrid for SWPS or HPS shall meet the requirements of international and national rural grid codes.

7.3.2 Design microgrid and wiring into households

Refer to IEC TS 62257-9-2 to design the microgrid of SWPS or HPS for isolated microgrid.

An example of design procedure of SWTS is provided in Annex G.

8 Safety issues

8.1 General

Refer to general IEC standards for electrical safety and electrical operation, and IEC TS 62257-5.

8.2 General

Safety awareness should be implemented throughout the overall system design, installation, operation, and maintenance.

Safety issues shall be seriously considered. These issues include personal safety, equipment safety, power system safety, and fire protection.

Safe work procedures shall be well developed and followed at all workplaces.

A principal contractor shall ensure work schedules and tasks are organized to provide safe working conditions for workers, equipment and systems.

Where a project involves the work of two or more employers or their workers, the principal contractor shall ensure compliance with the safety regulations and appoint a qualified individual to coordinate communication of implementation of the works, especially when raising up or lowering down a SWT.

It shall not be allowed to erect or lower down or maintain a wind turbine in the following conditions:

- Nights, unless proper lighting and work procedures are established and used;
- Thunderstorm;
- Sand blowing;
- When the wind speed exceeds the up-limit wind speed that allows raising SWT(s) specified by the turbine manufacturer;
- When ice or icing conditions are present;
- During other natural disasters (such as landslides), and so on.

8.3 Personal safety

8.3.1 Safety training and regulation following

All persons who are working on SWPS or HPS shall be well trained to undertake the on-site work, to be able to identify the risks related to works, recognize any early signs and symptoms of injuries and its potential effects on persons or equipment; and trained in the use of specific control measures, including, where applicable, work procedures, mechanical aids and personal protective equipment.

8.3.2 Basic safety guidelines

a) System installation personnel shall carefully read and be familiar with the safety contents provided and specially required by the wind turbine manufacturer and SWPS designer.

b) All persons not directly involved in the installation should stay clear of the area.

c) All persons on or near the tower should wear a safety helmet.

d) The tower should not be constructed near utility lines, especially not within a hemispherical space and the radius is 1,2 times of the height of the tower (base center to rotor center plus the length of a blade from rotor center to tip).

e) Only climb the tower with proper safety equipment.

f) When working on the tower, use a safety harness and tool belt.

g) Never carry tools or parts in your hands while climbing the tower.

h) Keep the amount of work to be done on the tower to a minimum.

i) Never stand directly below someone who is working on the tower.

j) Never work on the tower if alone on site.

k) Never climb the tower unless the turbine is shut down and the blades are stopped or barely rotating. The manufacturer will have provided the safe method for shut down of the SWT for performing inspections, service or maintenance including wind speed limits.

l) Stay clear of the tower in the presence or possibility of severe weather of any kind.

m) First aid for electric shock, burn, or acid splashes shall be available on site. Anyone who works at the site shall be familiar with first aid knowledge and familiar with the use of first aid equipment.

8.4 Equipment safety

8.4.1 SWT

a) Selected SWT shall comply with IEC 61400-2. Failure-safe mode shall be adopted in equipment and system design.

b) Customer-made tower shall meet the technical characteristics required by the selected SWT manufacturer.

c) SWT support structure (including guy wires) shall be appropriately earthed to reduce damage from lightning (see IEC 61400-2). To ensure the electrical system functions properly, the buried ground system shall have low impedance. The good grounding system should provide a low-impedance path for fault and lightning-induced currents to enter the earth, ensuring maximum safety from electrical system faults and lightning. The grounding system shall comply with the international and national standards, and system designed requirements. The overall effectiveness of a buried grounding system depends on many factors: the resistance of the earth (or earth resistivity), soil characteristics, soil temperature and type, and so on. Proper grounding rod materials and burying method shall be chosen based upon the site conditions to ensure the grounding system meets the system requirement.

d) All protection features of SWTs, and other equipment shall be in good functional states.

8.4.2 System current and voltage

a) The maximum DC voltage of the system should be lower than 750 V;

b) Wires and overcurrent protection devices shall be able to pass at least 125 % of the short-circuit current of the renewable energy power supply system;

c) Both undervoltage and overvoltage protection shall be provided;

d) The circuit of renewable energy power supply system, the inverter and the battery circuit shall have over-current protection;

e) Any break point of the system circuit shall be clearly marked with working voltage and short-circuit current.

8.4.3 Wiring and disconnection requirements

The electrical wiring should be consistent, the conductors shall comply with the color codes. The relevant technical conditions are:

a) If the cable may be exposed to the sun, anti-UV insulated cable should be used;

b) The connecting box should be placed in an easily visible position;

c) Each piece of equipment shall be connected to the ground and to the neutral if the system has a neutral;

d) Provide methods for disconnecting circuits in the power supply system;

e) For ungrounded conductors derived from the inverter, there shall be a disconnecting measure;

f) Both ends of the fuse should be able to disconnect from the power supply;

g) The switch should be easy to touch and clearly marked.

8.4.4 Grounding

Correct grounding and over-current protection can prevent and reduce damage caused by grounding faults.

a) If the voltage of the power supply system is > 50 V, the metal conductor shall be grounded. In a AC three-wire system, the neutral line at the center tap shall also be grounded.

b) Set up independent ground circuits to prevent fault current flows between different grounds. Setting a separate ground for SWT far away from the load can prevent damage from a lightning strike.

c) All outdoor equipment or exposed metal conductors should be grounded.

d) Equipment grounding conductor shall meet the applicable local or national codes.

e) The grounding conductor's cross section shall be sized with respect to the electric current, maximum voltage drop and temperature.

Safety regulations for other equipment in the system, such as PV array, diesel genset and battery bank, etc., shall be developed to meet the safety requirements with the equipment.

8.4.5 Other safety issues and anti-theft

a) Fences around SWT and other power generators shall be installed if necessary;

b) Practical measures shall be taken to prevent theft of equipment;

c) The grounding wire should be firmly installed to prevent theft. Check it regularly. Once the theft is found, remedial measures should be taken immediately.

d) The fence and control room shall be clearly marked with safety signs, such as "Warning! Electrical Hazard!" and so on.

8.5 SWPS safety for isolated microgrid

8.5.1 System safety

Carefully read the system installation instruction and prepare the auxiliary equipment, tooling and working procedures as necessary.

The system shall have operation "Stop" feature and should be designed with at least two methods for "Stop".

Cables and conductors shall be well selected to meet three fundamental requirements simultaneously: current carrying capacity, voltage drop and strength of cable.

a) Current carrying capacity

   The designed current carrying capacity should guarantee that the selected conductor will not heat up excessively during operation. The rated current carrying capacity and the maximum carrying capacity of a selected cable shall meet IEC 60287 series.

   Refer to the turbine manufacturer's manual for recommended wire and conduit sizes for the wire run.

   A hybrid system typically has two safety disconnects. The first disconnect is the PV disconnect (DC voltage), it allows the DC current between the modules (source) to be interrupted before reaching the inverter. The second disconnect is the AC disconnect, it is used to separate the inverter from the electrical grid. Both disconnectors shall be well sized.

b) Voltage-drop

   Voltage drop is defined as the amount of voltage loss that occurs through all or part of a circuit due to impedance (e.g., max 2 % or 3 % of rated system voltage). In off-grid renewable energy power systems, the most concerning is the drop of the voltage from the control room breaker box to the user's outlet at the farthest end of the grid. The voltage-drop shall not be more than the allowed percentage of the system rated voltage required per national standards.

c) Strength of cable

   Selected wire diameter should guarantee the strength of the cable.

The cables connecting SWTs to control-room shall avoid any damage by human activities and animals.

Typically, this is accomplished by using buried armored cable.

8.5.2 Extreme climate proof

SWTs and SWPS operating in marine environments should consider the lightning, typhoon, and corrosion resistance.

SWTs and SWPS operating under extremely cold, hot or sandy conditions should have special designs to meet these environment challenges.

8.5.3 High elevation for electronics

For SWTs and SWPS operating at high elevation (>2 000 m), a set of capacity descent factor K_i shall be applied based upon the electronic components to be used in the entire system.

$$P_i = P \times K_i \tag{5}$$

where

P_i is the equivalent capacity at high elevation (P is the rated capacity of an electronic component at normal conditions).

For low-voltage electric component in SWPS, K_i can be calculated as follows:

$$K_i = H^{-0,025 \Delta H} \tag{6}$$

where

H is the elevation of SWPS installed, km;

ΔH is the elevation difference with 2 000 m (2 km).

8.6 Protection against electric shock and fire

For protection against electric shock the requirements of IEC 61140 shall apply.

Fire-fighting equipment (at least a sand bin and preferably extinguishers) shall be provided. The room doors shall open outwards and be fitted with releasing devices, such as panic hardware, fire exit hardware and exit locks, an emergency stop-switch shall be installed.

No smoking and no live flames in the battery room.

The battery room shall have good air circulation and be separated from other rooms such as control room. There shall not be any personnel living in the battery room.

9 SWT and SWPS installation

9.1 General

9.1.1 Overview

Applicable safety rules in Clause 8 shall be followed.

For any potential installation site, legal restrictions shall be carefully checked and obeyed, such as maximum height restriction from aviation administration.

The complexity of installation of SWPS varies based upon the type of SWPS designed, the wind turbine selected and the site conditions. The installers shall be well familiar with the type of turbine that will be installed.

When receiving the delivery, the boxes and contents should be checked for parts with packaging list and any signs of damage.

9.1.2 General installation methods

The methods of SWPS installation are determined by the structure of SWTs and types of selected tower, see Table 5. Some of them can be installed with manual labor, while others may need powered equipment, such as a truck or crane.

Table 5 – Installation methods of different SWPSs

Type of SWPS	IES*	Isolated microgrid
Smaller	Man power	Powered equipment
Larger	Powered equipment	Powered equipment
*IES: Individual electrification system.		

"Smaller" SWPS means the systems' capacity is small (up to a few kW) and can be erected and installed without powered equipment (such as a crane); "Larger" SWPS requires that its erection and installation shall use powered equipment. It is hard to classify these two kinds of SWPS in exact capacity since it is dependent on the structure and tower types of selected SWT in the power system.

The right installation method is recommended by turbine and tower manufacturer.

The user shall strictly follow the instructions of installation suggested by the turbine and tower manufacturer.

The installation personnel shall follow this document and other related technical documents, and comply with the local regulations for safety requirements and labor protection.

Except for the very small SWPS, the installation should be carried out by professional technicians who have received training with necessary site working knowledge and practices related to SWT and SWPS. A team leader should be appointed, who is the only person who will direct the actions during installation.

9.1.3 Rooftop installation

It is generally not recommended to install a wind turbine on the roof of a building. If it shall do so, during the system design stage for rooftop mounted SWT, the roof structure (or building structure), load support capability and potential vibration with the maximum wind load shall be evaluated by civil engineering professionals. Never install a turbine or turbine tower on the wall of a building. Any required improvements on the buildings shall be done before the starting of SWT installation.

Warning: Rooftop installations are seldom successful and are not recommended.

9.1.4 Verticality

Verticality of a SWT will affect its performance. After the assembly and the installation of SWT, make sure the tower is plumb, and check its verticality during regular maintenance and after any severe weather conditions.

9.2 Installation of SWPS of isolated microgrid

9.2.1 Transportation

Equipment of SWPS shall be well packed based upon the shipping methods, such as ocean vessel transportation and/or inland truck or train shipping.

The shipping methods in remote rural areas shall be considered carefully, where there may be no road, or a truck may not be allowed to deliver the equipment to the installation site. Sometimes, the equipment shall be disassembled into small pieces so as to be moved to the site by manpower or animals. The project developer shall clearly state this requirement when ordering the equipment from manufacturers.

9.2.2 Preparations

a) Checking before installation

   1) The installed SWPS should have the documentation that the SWT complies with the requirements of IEC 61400-2 and any other relevant local or national standards, packing list, installation instructions and Operations and Maintenance manuals provided by the equipment manufacturers;

   2) The parts and equipment shall be carefully checked with packing list; be sure everything is correct and in good condition;

   3) Check with equipment manufacturers for any updates before installation;

   4) Choice of concrete foundation type and its design should be governed by the Soil Bearing Capacity (SBC) of the installation site.

b) Other preparations

   The installation site should not have any unsafe factors which may lead to hazards for personnel or equipment, and shall meet the following requirements:

   1) The access roads are clear and without any obstacles;

   2) The parts of SWPS and all equipment ready for installation shall be carefully stored on site to avoid any dangers to the installation staff;

   3) The storage, using and moving of installation tools should not be dangerous to people and not damage the parts of SWPS;

   4) Installation should be done on days when the wind speed is below the maximum wind speed recommended by the SWT manufacturer;

   5) The depth of the frozen earth should be considered when the installation is in winter seasons.

9.2.3 Infrastructure

a) Road

   The contractor shall perform a site investigation before system design and installation. Usually, it is not feasible to build a road to deliver equipment for a small off-grid Isolated Microgrid to the project site. A very important consideration in system design is easier installation on site due to its “remote” nature.

b) Powered equipment

   For small SWPS, using powered heavy equipment in the installation in remote sites shall be avoided because such equipment may not be available locally, and considering the financial cost in further O&M. It is better to choose SWTs for which erection and installation can be implemented just by man-power or simple machinery.

   If the powered equipment, such as a truck or a crane, will be needed during the installation, the local availability of the powered equipment shall be carefully checked before system design and installation. Use of powered equipment shall not just be evaluated during installation, but for later maintenance as well, from both technical and economic aspects.

c) Water supply

Water is necessary in building concrete foundations and rooms. Check water availability and quality (e.g., salinity) on site before installation.

9.2.4 Civil works

a) General

Most SWPS need concrete foundations for SWTs (except some small SWTs may use spiral anchors).

Building concrete foundations for a SWT shall follow the foundation specifications designed by the manufacturer. The requirements of cement specifications, specifically the curing period for different seasons, shall be followed.

Installers shall follow the requirements from the turbine manufacturer about the foundations regarding layout, dimensions, and depth. In areas with deeper frost, the anchor and base pad thickness shall be increased to extend the pads below maximum frost depth. It may be necessary to check with the turbine manufacturer for more detailed technical information. Pad designs provided by turbine manufacturer are suitable for a broad range of soil type and strength, but non-cohesive soils such as sand will require larger pads to resist vertical loads exerted by guywires and raising cables. The installer shall consult the turbine manufacturer in such cases for proper pad sizes.

Minimum cure time for pads is 14 days, but for maximum strength 28 days is recommended. For both strength and surface finish quality, it is important to control the cure process. In hot conditions pad tops should be covered with burlap or similar material and watered down several times a day, at least for the first 3 to 4 days. In cold conditions the concrete should be covered and insulated to prevent freezing. The tower shall never be erected before the number of curing days required. For specific recommendations refer to a standard construction manual for concrete techniques.

The amount of cement used should not be lower than required by the instructions. The mixing ratio should be accordance with the requirements in the instructions.

If the construction is in winter, it is necessary to use a higher amount of cement and add antifreeze to the mixture. During the curing period, the pad shall be well covered for heat preservation.

b) Free-standing tower

For a free-standing tower, the horizontal levelness and overall consistency of the top surface of the foundations shall be strictly Maintained. After assembly of the SWT, the overall verticality shall meet the requirement in 9.1.4.

c) Tilt-up tower

For a tilt-up tower, assure the exact elevation for pads in the center and both sides (right and left) along with the raising direction. Refer to Figure 9. Manufacturer directions for foundation height and offsets shall be followed to the tolerances required.

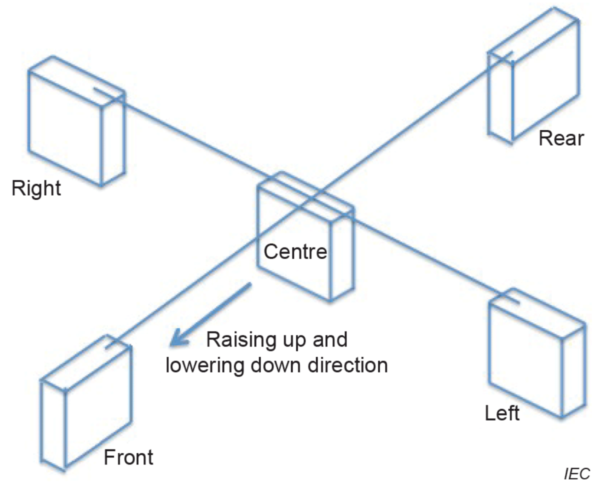


Figure 9 – Pads for tilt-up tower

For a tilt-up tower, the tower site shall allow ample room for laying the tower down. There shall be a clear area that will not interfere with either the tower structure or the guywires when the tower is horizontal.

For a tilt-up tower, it is recommended that the tower raising and lowering direction is aligned with the primary wind direction at the site. This will help "push" the tower over and make the raising and lowering easier.

9.2.5 Installation of equipment

The structures of SWTs, the combinations of turbine with towers, and the assembly procedures of SWPS vary significantly from one manufacturer to another. The instructions from equipment manufacturer regarding structures of SWTs and the assembly procedures shall be strictly followed.

The installation plan shall be developed based upon the SWPS manufacturer's instruction, all installation tools and equipment shall be listed and ready on the site.

The erection of towers is a highly specialized field and should be performed only by experienced personnel with proper equipment. It is important that the personnel have adequate insurance coverages. It is also important that erectors have an adequate safety/training plan that includes such items as fall protection training, personal protection equipment training, and equipment that meets safety requirements. The site- specific technical procedures and a rigging plan that define all the critical steps that are involved prior to starting the project shall be prepared and submitted, and the installer shall ensure that the technical procedures and rigging plan are being followed as the work is being performed.

The wind condition on the day of erecting SWTs shall meet the wind speed stated by the turbine manufacturer (i.e., shall not exceed the maximum wind speed allowed to erect a SWT).

a) Mechanical

   It is suggested to use a forklift, tractor (with a frontend loader), or crane to move heavy tower sections.

   Choose the lifting direction on the installation spot for the tilt-up tower structure if applicable.

   Strictly follow the instructions and installation sequence suggested by the manufacturer to assemble the tower and wind turbine and erect the tower and install the wind turbine on the tower.

   If a vehicle will be used to pull the raising cable during tower tilt-up, an unobstructed pathway of sufficient length will be required for vehicle travel. The surface of this pathway shall provide sufficient traction for the vehicle to be used, and it shall allow straight travel of the pull-up vehicle.

Use a torque wrench on all connecting bolts and nuts to confirm the proper tightening torque recommended by manufacturers. A method of "full contact plus one-quarter turn" on the heavy-duty nuts may be used if a torque wrench is not available.

PAL nuts shall be applied on tower assembly where required by tower manufacturer.

SWT shall be in braking condition during tower lifting or lowering if the turbine is assembled on the tower and then to lifted together with the tower.

Maintaining a plumb tower during erection eliminates the need for time-consuming adjustments later. Final tensioning of the guy wires and a plumb check are performed after the entire tower is erected. After assembling the SWT, the overall perpendicularity shall meet the requirement in 9.1.4.

In the case of bad weather during the erection, emergency protection measures should be taken or stop lifting.

When lifting and lowering a tower, it is prohibited for anyone to stand under the lifting objects.

All fasteners and connecting pieces and the rotating part of SWT shall be checked before test running.

For a tilt-up guyed tower, always do a test raising operation of the tower without an installed turbine.

For marine environments, some critical items such as guy-wires and double-grip clips, are simply not available in corrosion-resistant form. Special corrosion inhibiting grease should be applied to guy cables and hardware and should be renewed periodically during regular tower inspections.

b) Tension

The most commonly used guy wires are EHS Steel guy wires. Proper pretension shall be applied to the guy- cables of the tower. It is recommended that the guy wires should have an initial tension (pre-load) of approximately 10 % to15 % of its ultimate breaking strength to stretch out the slack in them. The exact amount of pre-load depends on the type of guys used (length, size and weight per unit), and how high up in the tower they are attached. Depending on the height of the tower, the right diameter of the guy wires shall be chosen so that they can handle the load of the tower. Following the instruction about the guyed wire recommended by the turbine manufacturer is very important.

There are several methods of measuring guy tension with varying degrees of accuracy. For small guys whose diameter is up to 18 mm, a shunt dynamometer calibrated for the size and type of strand is often used. Guy tensions should be checked in conjunction with the tower alignment. These tensions should be measured at the anchor end and compared to the specified values. It is important to remember that they are dependent on the ambient temperature.

If a shunt dynamometer is not available, some simplified method may be adopted, such as the "oscillation method", it can be used to identify the approximate tension of guyed wires based upon the length and mass of the wire and the frequency of vibration that is briefly described in Annex H.

c) Electrical

Installing lightning arresters between the wind turbine and the charging controller is strongly recommended. A weather-tight switch box with fuses which match the specification of turbine's three-phase output may be used for some types of SWTs. The fused disconnect switch is normally installed at the base of the tower.

Do not install a "short circuiting switch" that will provide dynamic braking of the alternator. These switches can be easily misused, leading to serious damage to the alternator.

Follow manufacturer's instructions in wiring the SWT. Do not install fuses in the line between the alternator and the controller unless approved by the manufacturer. Some turbines will require a shorting switch for maintenance. Check with the manufacturer.

The charging controller shall be installed indoors, near the main breaker enclosure, if possible, unless the controller is designed to be weatherproof. Certain clearance is required on the top, bottom, and sides of the charging controller to ensure adequate air flow through the enclosure.

Strictly follow the instructions, procedures, and sequence to connect equipment electrically, always have the wind turbine fully disconnected and the circuit breaker switched to "off" before making the charging controller connections.

All wiring should conform to the national electric code or other governing local electrical code. The use of electrical conduits for wiring between components is highly recommended. All terminations should be coated with an anti-oxidation compound to prevent corrosion.

All loads should be equipped with fuses or circuit breakers to avoid hazards from accidental short circuits.

10 Tests and acceptance

10.1 General

Refer to IEC TS 62257-6 and IEC TS 62257-9-1 for SWPS tests and acceptance.

SWPS tests may include the individual equipment test, system performance tests, and acceptance test.

10.2 Individual equipment test

The contractor shall test each individual piece of equipment of the SWPS during the installation for debugging.

The performance of each individual piece of equipment shall meet the requirements and specifications described in the contract.

The contractor shall develop the procedures for individual equipment test and take records and test results during SWPS tests.

10.3 System self-test

The contractor shall do the SWPS self-test and debugging based upon the contract prior to acceptance test and commissioning. The tests should be carried out in the following sequence:

a) system performance test without load; and

b) system performance test with load.

The contractor shall develop the procedures for system self-test, all test procedures and results shall be well documented.

10.4 Acceptance test

10.4.1 General

An acceptance process shall be performed to ensure that the SWPS installed meets all requirements of the general specification and contract.

SWPS acceptance procedure shall refer to IEC TS 62257-6 technical specifications. Specific issues for the acceptance of the different SWPSs shall be addressed in the document specific to these generators.

The acceptance test procedure may consist of the following steps, as shown in Figure 10.

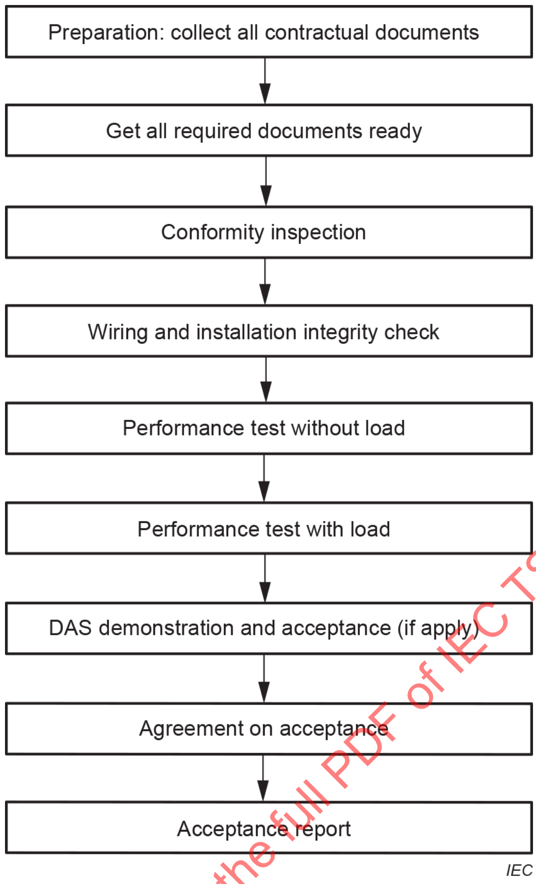


Figure 10 – Acceptance test procedure of SWPS

10.4.2 Preparation

The project contractor shall collect all contractual documents which have to be supplied by the manufacturers and subcontractors.

10.4.3 Documentation

The project developer shall verify that all the required SWPS documents (manuals, spare parts, drawings, procedures, warranty contracts, list of tests, etc.) have been provided and comply with the contractual requirement of the general specification. If the local language is different from the contractor or equipment supplier, the operation manual shall be translated into local language.

10.4.4 Commissioning

The acceptance test may be carried out first for commissioning the SWPS before the whole power system to be commissioning. The following steps may be followed:

Step 1: Contractor shall develop a procedure for acceptance test and commissioning, including: purpose of test; items to be tested; methods of test; instrument to be used in testing, expected results based upon the specifications described in the contract;

Step 2: Evaluation of the conformity of the installed system with the approved design;

Step 3: Wiring and installation integrity check;

Step 4: SWPS performance test.

Since the SWPS is only one of the power generators in the hybrid power system, the performance test shall be well designed based upon the real configuration of the hybrid power system and follow the instruction from SWT manufacturer. The performance test process and results shall be well recorded and documented. An example of a commissioning records sheet for SWT is presented in Annex F, Table F.1 and Table F.2.

Any underperformance of the system shall be assessed by engineering consultants. A proposal for correction shall be made to the project developer who shall decide whether to implement the corrective actions or not.

10.4.5 Agreement

A letter of agreement of commissioning of SWPS shall be signed by the different parties involved in the project: the project developer/project contractor, owner/operators, etc.

This agreement could be confirmed through two steps:

- a provisory agreement signed immediately after the short-term performance testing;
- a final agreement signed after the long-term performance.

11 Operation and maintenance

11.1 General

This clause only gives general guidance for the preparation of operation and maintenance procedures for SWPS. Examples of such procedures are given in Annex D.

11.2 Safety

Attention should be given in the operation and maintenance procedures to the following safety requirements:

a) Emergency shutdown procedure;
b) Obey all warning signs;
c) Shut system down and interrupt SWT currents according to the manual shutdown procedure.

11.3 Operation and maintenance procedures

SWTs do not generally require control actions in normal operation. The most important operation procedures for SWTs are those related to switching on and shutdown for emergency and maintenance purposes.

Operation and maintenance procedures should include the following:

a) a short description of the function and operation of all installed equipment. More detailed information should be available from the manufacturer's documentation;
b) emergency and maintenance shutdown procedures;
c) periodic maintenance requirements including procedures and schedule. Annex D gives an example of a maintenance schedule;
d) equipment manufacturer's documentation (data sheets, handbooks, etc.) for all equipment supplied.

The SWPS performance shall be recorded on a long-term basis (seasonal, or annual if relevant) as a part of the entire off-grid power system, especially for isolated microgrid. Any abnormal downtime, failures, damages, and repairs should be documented and analyzed.

11.4 General inspection, routine and troubleshooting

11.4.1 Inspection

The manufacturer's instructions for inspections after installation and for ongoing maintenance shall be followed. Inspections should be done on days when the wind speed is not larger than the highest wind speed specified by the SWT manufacturer for maintenance.

11.4.2 Check list

A check list for inspections shall be provided by the SWT/SWPS manufacturer, which at least covers the following:

- each of the anchor points;
- blades' cracks;
- torque on the blade nuts;
- check the torque on each of the bolts;
- turbine protection mechanism;
- the connections on all ground rods and hardware;
- listen to the sound of the machine as it speeds up;
- watch for any new or significant vibration;
- lubricant leaking and refill if need;
- tension of guyed wire for tower if applied;
- inspect the wire run, particularly all electrical connections;
- use a multimeter to check that the three legs of the AC output of the wind turbine are in balance;
- check conditions of all wiring connections into and out of the controller.

Only qualified personnel with proper safety equipment should climb the tower. Never climb the tower when the rotor is rotating.

11.5 Troubleshooting

SWTs and equipment used in SWPSs vary from one to another. The possible equipment and system problems and causes, the diagnosis and corrective action methods are quite different. The only source for this information is the equipment manufacturers and system designer.

The turbine manufacturer shall provide a guide to help to identify the cause of operational problems with the SWT and the controller, the contractor shall provide a guide to help to identify the cause of operational problems for the SWPS and HPS. The manufacturer shall provide a troubleshooting list of items that can be checked before calling service personnel. Items in the list shall be such that they could be checked by a trained operator but not requiring specialized test equipment or trained service personnel.

An example of troubleshooting is given in Annex E. For problems or symptoms not found in the guidance, the manufacturer or system designer shall be contacted as soon as possible to provide advice.

Phone numbers and email addresses of equipment manufacturers, system designer and contractor shall be readily available for the operators.

12 Marking and documentation

12.1 Markings and signs

12.1.1 General

All markings and signs shall comply with ISO 3864-1 and IEC 61400-2.

12.1.2 Equipment marking

All electrical equipment shall be marked according to the requirements for marking in IEC standards or to applicable local standards and regulations. Markings should be in the local language or use appropriate local warning symbols.

12.1.3 Requirements for signs

All signs required in this clause shall:

a) comply with IEC standards;
b) be indelible;
c) be legible from at least 0,8 m unless otherwise specified in the relevant clauses;
d) be constructed and affixed to remain legible for the life of the equipment it is attached or related to;
e) be understandable by the operators.

12.2 Labelling

12.2.1 Labelling of SWT

A label containing the text of “Manufacturer name, model of the equipment, rated annual energy, rated sound level and rated power”, shall be displayed at a visible place. Refer to Annex C for an example of SWT label.

12.2.2 Labelling of disconnection devices

a) General

   Disconnection devices shall be marked with an identification name or number according to the wiring diagram.

   All switches shall have the ON and OFF positions clearly indicated.

b) Disconnecting device

   The SWT main switch shall be provided with a sign affixed in a prominent location with the following text: ‘SWT MAIN SWITCH’.

12.3 Documentation

The SWPS designer shall prepare the following documents and a set of copies shall be delivered to the system owner:

a) A final detailed system design technical document with basic circuit diagram that includes the electrical ratings of the SWPS and required information.
b) SWPS or parts certification as required by relevant authorities and provided by manufacturer(s).
c) A copy of the emergency shutdown procedure including the location of relevant switching devices.
d) A copy of the operation regulation and maintenance procedures in accordance with Clause 10, in local language.

Annex A
(informative)

Main characteristics of an off-grid wind turbine

A.1 Example of battery charging horizontal axis SWT's characteristics, see Table A.1

Table A.1 – Example of battery charging horizontal axis SWT's characteristics

Items	Specification
Performance	
Start-up wind speed	3,1 m/s
Cut-in wind speed	3,5 m/s to 4,5 m/s
Rated wind speed	12,4 m/s
Rated power	7,5 kW
Cut-out wind speed	None
Furling wind speed	15,7 m/s
Maximum design wind speed	54 m/s
Mechanical	
Type	3 Blade upwind
Rotor diameter	7 m
Weight	463 kg
Blade pitch control	POWERFLEX®
Over-speed protection	AUTOFURL
Temperature range	-40 °C to +60 °C
Electrical	
Output form	48 V, 120 V, 220 V or 240 V DC nominal
Generator	Permanent magnet alternator
Output control system	VCS-10 Charge Controller

A.2 Example of battery charging vertical axis SWT's characteristics, see Table A.2

Table A.2 – Example of battery charging vertical axis SWT's characteristics

Items	Specification
Performance	
Rated power	10 kW
Max power	12 kW
Rated wind speed	12 m/s
Cut-in speed	2 m/s
Cut-out speed	25 m/s
Survival wind speed	55 m/s
Physical parameters	
Rotor diameter	6 m/s
Rotor height	6,2 m/s
Rotor weight	2 375 kg
Tower height and weight	5,5 m (1 000 kg)
General parameters	
Type	PMG 3 phase
Rated voltage	250 V AC
Rated current	23 A AC
Protection level	IP 54
Controller output	
Output voltage (on-grid)	DC 50-375 V
Output voltage (off-grid)	DC 110 V
Over speed protecting braking system	
Speed control style	Pitch control system
Brake style	Automatic hydraulic brake

Annex B
(informative)

Wind shear exponent, α

The wind shear exponent varies with the time of day, season, terrain and the stability of the atmosphere. Shear is low where these are minimum surface roughness and high where there are numerous objects to disturb the air flow.

Table B.1 – Surface roughness and lengths and the wind hear exponents α

Terrain	**Surface roughness length** m	**Wind shear exponent** α
Ice	0,00001	0,07
Snow	0,0001	0,09
Calm sea	0,0001	0,09
Coast with on-shore winds	0,001	0,11
Snow covered crop stubble	0,002	0,12
Cut grass	0,007	0,14
Short grass prairie	0,02	0,16
Crop, tall grass prairie	0,05	0,19
Hedges	0,085	0,21
Scattered trees and hedges	0,15	0,24
Trees, hedges, few buildings	0,3	0,29
Suburbs	0,4	0,31
Woodlands	1	0,43
Related to a reference height of 10 m. Adapted from "Characteristics of the Wind by Walter Frost and Carl Aspliden", *Wind Turbine Technology and Windenergie: Theorie, Anwendung Messung* by Jens-Peter Molly.		

SOURCE: Paul Gipe, *Wind Energy for the Rest of Us: A Comprehensive Guide to Wind Power and How to Use It*, 2016.